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Technical Report 475

ADAPTIVE DECISION AIDING IN COMPUTER-ASSISTED INSTRUCTION: ADAPTIVE COMPUTERIZED TRAINING SYSTEM (ACTS)

Rosemarie Hopf-Weichel, Denis Purcell, Amos Freedy, and Luigi Lucaccini
Perceptronics, Inc.

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This report describes the results of the first year's effort of a 3-year program to develop and evaluate a new Adaptive Computerized Training System (ACTS). This combines principles of artificial intelligence, decision theory, and adaptive techniques for teaching the procedures necessary to troubleshoot electronic circuits. ACTS emphasizes the realistic simulation of maintenance problems and focuses on enhancing the acquisition of decision-making skills which underlie successful electronic troubleshooting performance. The ACTS

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tracks a student's diagnostic and decision value structures, compares them to that of an expert, provides individualized feedback and help, and structures subsequent learning experiences. It is designated to facilitate transfer of these skills to an actual military environment. Preliminary studies indicate that the ACTS does teach students to make more effective decisions troubleshooting electronic equipment. A large-scale study to further evaluate the training potential of the ACTS is planned for the second year, as well as to assess transfer to actual equipment following training with the ACTS.

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Rosemarie Hopf-Weichel, Denis Purcell, Amos Freedy, and Luigi Lucaccini
Perceptronics, Inc.

Submitted by:
James D. Baker, Chief
MANPOWER AND EDUCATIONAL SYSTEMS TECHNICAL AREA

Approved by:

Edgar M. Johnson, Director
ORGANIZATIONS AND SYSTEMS
RESEARCH LABORATORY

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333

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FOREWORD

The Computer-Based Instructional Systems Team of the Army Research Institute for the Behavioral and Social Sciences (ARI) performs research and development in areas of instructional technology that apply to military training. A special research focus is the use of computer-based systems, which can provide highly individualized training and can therefore improve training effectiveness as well as reduce training costs and time.

This report describes the results of the first year of a 3-year effort to develop and evaluate a new Adaptive Computerized Training System (ACTS). The ACTS combines the principles of Artificial Intelligence, decision theory, and adaptive Computer-Assisted Instruction to provide improved maintenance training. In order to accomplish this research, ARI's resources were augmented by contract with Perceptronics, Inc., an organization selected as having unique capabilities for research and development in this area.

The research effort is responsive to the requirements of RDT&E Project 2Q762722A764, Training and Education, as described in the ARI FY 79 Personnel Performance and Training Program.

Joseph Zeidner

JOSEPH ZEIDNER
Technical Director

ADAPTIVE DECISION AIDING IN COMPUTER-ASSISTED INSTRUCTION: ADAPTIVE COMPUTERIZED TRAINING SYSTEM (ACTS)

BRIEF

Requirement:

The Adaptive Computerized Training System (ACTS) is being developed to provide generalizable diagnostic skills to maintenance trainees.

Current Army maintenance training is largely equipment-specific. The student first learns the step-by-step procedures for locating a malfunction in a specific item of equipment, then practices and is tested on the equipment itself. Skill thus learned does not transfer readily to other equipment. Also, equipment that could be used operationally is required for training, instructors must spend time inserting malfunctions into equipment instead of teaching, and students spend time assembling and disassembling equipment that should be spent experiencing a variety of faults.

ACTS Training:

The ACTS applies principles of artificial intelligence, decision theory, and adaptive computer-assisted instruction to Army maintenance training. The student's task in ACTS training is to troubleshoot an item of equipment by making various test measurements and replacing the malfunctioning part. ACTS simulates the electronic malfunction, with no actual equipment required. It also uses artificial intelligence techniques to develop mathematical models of both the student and the expert performer. These models can serve as a basis for evaluating student performance. Previous research has shown the feasibility of the ACTS approach. This effort focused on improving ACTS software and courseware, and on initiating evaluation of the improved system.

The new software developed permits simultaneous use of the ACTS by multiple students, simultaneous use of different items of equipment, and simplified techniques for modeling new items of equipment. Revised procedures for modeling student and expert performance permit the presentation to the student of feedback which is based on a comparison of student and expert models. A plan for the installation of the ACTS at the U.S. Army Signal Center at Fort Gordon, Ga., was developed, which will permit the evaluation of the ACTS in an operational training setting. Finally, a pilot experiment was performed to de-bug ACTS courseware, software, and experimental procedures.

Utilization:

ACTS research and development will continue for an additional 2 years, culminating in a cost and training effectiveness evaluation of the system in an ongoing course of instruction at the U.S. Army Signal Center and Fort Gordon. If successful, it is expected that the system will be implemented in Army schools providing maintenance training.

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1. OVERVIEW

1.1 Objectives of Phase I

This report describes the results of the first year's effort of a three-year program to develop and evaluate a new Adaptive Computerized Training System (ACTS). The overall effort combines the principles of artificial intelligence, decision theory, and adaptive computer-assisted instruction so as to result in improved training techniques for use with Army recruits in the learning of electronic maintenance troubleshooting procedures. In particular, ACTS is intended to focus on enhancing the acquisition of decision-making skills which underlie successful electronic troubleshooting performance. An important aspect of ACTS is the emphasis on realistic simulation of maintenance problems during training so as to increase the potential for transfer of training to field situations. ACTS' design incorporates an adaptive computer program: (1) to track students' diagnostic and decision value structures for comparison to that of an expert, (2) to develop appropriate individualized feedback, and (3) to structure subsequent learning experiences.

Major objectives of Year 1 were:

(1) To develop new software which provides for simultaneous use of ACTS by multiple students, which permits simultaneous use of different circuits, which provides for interchangeable circuit modules, and which is compatible with equipment and computer systems available at the Fort Gordon Army Signal School.

(2) To develop new courseware which includes a more powerful decision model and improved instructional text, and which

provides for utility driven performance feedback and variable problem presentation modes.

(3) To develop a plan for ACTS transfer to a military training environment, namely the Army Signal School at Fort Gordon, Georgia.

(4) To conduct experimental work in order to evaluate the effectiveness of the new ACTS.

1.2 Approacn

Computer-assisted instruction continues to represent a promising avenue both for research on the basic instructional processes and for the development and integration of artificial intelligence techniques to enhance individualized instructional processes in a number of areas, including training of decision-making and problem-solving capabilities. ACTS is a particularly important example of such training technology. Utilizing adaptive, computer-based techniques, the ACTS permits individualized training in an electronic maintenance environment. The system has been successfully implemented in the laboratory and subjected to limited testing.

A major portion of the first year's effort consisted of expanding the system to accommodate multiple tasks and multiple students, by developing multiple circuit capability and improving the ACTS' software organization. As a result of previous experimental findings, the utility models of the original ACTS were replaced by more efficient multi-attribute utility (MAU) models and the ACTS was supplemented with production rules. In addition, the existing software was modified and expanded to provide for simultaneous use of multiple students and multiple circuits, as well

as for interchangeable circuit modules. Evaluation of the ACTS is being documented, and a preliminary study was conducted to evaluate the training effectiveness of the ACTS and the generalizability of the results obtained with the ACTS. The software is compatible with equipment in use at the Fort Gordon Army Signal School.

1.3 Accomplishments

The accomplishments of the first year tasks focus on four areas. The following is a summary of the work accomplished in each area.

1.3.1 Development of New Software.

New ACTS Design. A new version of the ACTS has been designed, coded and tested. The new ACTS contains the following main features.

Multiple Students. The new design allows two or more students to use the system simultaneously. The students can run on fully independent instructional sequences, subject only to memory constraints. Additionally, an experimenter can communicate with the ACTS during system execution via the teletype I/O channel.

Multiple Circuits. Each set of circuit modules is circuit specific. That is, any circuit is fully represented by the circuit simulation model, together with the instructional text module for that circuit. Consequently, any student using the ACTS may interact with it independently of whatever circuit has been modeled, subject only to secondary storage limitations. New circuits can be modeled by creating a circuit simulation model and instructional text module specific to that circuit, using a fixed structure. A separate document (Perceptronics' Report PDCMDM-1076-79-7, 1979) describes the necessary steps for modeling new circuits.

Parameterized Circuit Model. Each circuit has a simulation model assocciated with it, consisting of an overlay with a fixed structure. Creating a new circuit model involves filling in the specific parameter values, such as measurement outcomes and the number of faults for the new circuit. This is done by utilizing an existing circuit model as a guide. The process requires only that the new circuit be at a comparable level of complexity to those already modeled. Since all circuit models have standardized structure and parameters, the development of new circuits for the ACTS is relatively simple.

Variable Mode Problem Presentation. Problems are characterized in terms of their difficulty level. Since it is assumed that the sequencing of problems may have an effect on performance, there are two modes in which the problems are presented to the students. In the first mode, the problems are presented randomly, regardless of their difficulty level; in the second mode, the presentation sequence is fixed, beginning with all problems having simple-to-locate faults, continuing in a graduated manner with problems having intermediate levels of difficulty, and ending with problems having faults which are very difficult to locate.

1.3.2 Multi-Attribute Utility (MAU) Decision Model. A multi-attribute utility (MAU) decision model, exhibiting efficient decision-making behavior for troubleshooting electronic circuits, has been developed. This multi-attribute model is superior to earlier models because it can capture circuit troubleshooting behavior independent of circuit type, thus providing a more generalized behavioral representation than was the case in the earlier version of the ACTS. The attributes used in the present system include cost, and information gain measures. Cost is an estimate of the time and materials required to take a particular measurement or replace a module, and varies depending on the action involved. Fault information gain refers to the proportion of faults that are expected to be eliminated

by a particular measurement or module replacement. Fault information gain is an important attribute, in that some measurements or replacements are more efficient than others in reducing the set of all possible faults. Commercial information gain indicates the degree to which the remaining possible faults will be "clustered" within commercial circuit components, given a particular measurement. (Since it is easier to troubleshoot a circuit when all remaining possible faults are clustered in a couple of circuit components rather than scattered throughout, a measurement which will permit greater proportional circuit module isolation, is more efficient than one not having this capability.) The software is designed in such a way that new attributes can be added, or any of the existing attributes altered, if the need arises.

1.3.3 Instructional Text. To develop instructional text, the circuit module designer performs a conventional task analysis on the decision-making troubleshooting skills required for a given circuit. The result is a sequence of skill-based objectives that must be translated into teaching units. These units generally consist of text material, an optional question-answer session, and a multiple-choice test, and are designed to improve the circuit knowledge of the student. The student is guided through these units until the required level of circuit knowledge necessary to begin troubleshooting is obtained.

Instructional text is also embedded in the troubleshooting unit in the form of preliminary lecture material, feedback messages, and material provided by means of a "Help" option.

Utility Driven Performance Feedback. During the terminal troubleshooting instruction, feedback is derived from the MAU model weights while the student is being trained. Information concerning the degree of convergence, proximity to the expert model, and relative weighting difficulties

can be assessed from the student and expert models. This information, in turn, is used to encourage consistency, to teach the student to mimic the expert, and to adjust the significance with which displayed attribute information is viewed.

1.3.4 ACTS Transfer to Military Training Equipment. A plan for the installation of the ACTS on an operational Army computer-based training system was developed, and is documented in Perceptronics, PDIP-1076-79-6. The document describes the plan for installation of the ACTS in the Computerized Training System at Fort Gordon, Georgia. It includes a study of the current configuration and operation of the Training System, identifies expected problem areas, examines transfer alternatives, and presents a complete program plan to accomplish the ACTS transfer.

In addition, a site visit to Fort Gordon was made to determine the scope of the existing training program and to perform a needs analysis, based on the entry level of the students and the instructional objectives of the U.S. Army Signal School at Fort Gordon.

1.3.5 Experimental Study. A pilot experiment was performed, which served two major purposes: the first was to fine tune the ACTS and the methodology for performing the large-scale study designed for the following year and the second purpose was to obtain preliminary data to assess the training value of the ACTS.

As a result of this study, several improvements were made to the software, including the design of a new print-out routine for obtaining performance measures. Despite some inadequacies in the system, the data obtained from three college students suggest that the ACTS does indeed train the higher-order decision-making skills necessary to troubleshoot electronic circuits. Details of the experimental method, and the results obtained, are described in Chapter 3.

1.3.6 Directions for the Future. While initial results are particularly promising, the ACTS still remains to be tested in the full-blown operational training environment. It is anticipated that such a study will be undertaken in the near future which will include, among other things, an assessment of: the transfer of skills which occurs with the troubleshooting of real, rather than simulated, equipment and the long-term retention of skills. It is hoped that field studies will bear out our conviction that ACTS can make a significant practical contribution to the training of electronics maintenance personnel. It should not be overlooked that the basic approach outlined above may have implications for improving the quality of human decision performance on related tasks, although the applicability of ACTS outside the electronics maintenance training area remains to be explored.

2. THE ADAPTIVE COMPUTERIZED TRAINING SYSTEM

2.1 Overview

The Adaptive Computerized Training System (ACTS) focuses on improving and sharpening higher-order cognitive skills in electronics troubleshooting. The application of decision models to training is reviewed prior to presentation of the features of the ACTS.

Although maintenance tasks rely heavily on a technician's knowledge and training regarding the maintained systems, such tasks can be viewed primarily as decision tasks. If the technician possesses sufficient knowledge of system parts and functions, he applies it by making a series of decisions about which symptoms to look for, whether to repair or replace a malfunctioning part, and so on. ACTS is used in electronics maintenance training to address the quality of such decisions and the process of generating and choosing from among alternatives, rather than for the learning of specific procedural sequences.

ACTS incorporates an adaptive computer program which learns the student's diagnostic and decision value structure, compares it to that of an expert, and adapts the instructional sequence so as to eliminate discrepancies. An expected utility (EU) or a multi-attribute utility (MAU) model is the basis of the student and instructor models which, together with a task simulator, form the core of ACTS. Earlier versions of the system used an expected values model (Freedy and Crooks, 1975; Crooks, Kuppin and Freedy, 1971). The student model is dynamically adjusted using a trainable network technique of pattern classification. The training content (instructions) and problem presentation sequence are generated with heuristic algorithms. ACTS is implemented on an Interdata Model 70 minicomputer and uses interactive graphics terminals for man/machine communication.

The present training system focuses on electronic troubleshooting. The student's task is to troubleshoot a complex circuit by making various test measurements, replacing the malfunctioning part, and making final verification measurements. The model of the student evaluates the student's selection of measurements and replacement of circuit modules. Troubleshooting provides an excellent application for the ACTS methodology because it is heavily dependent on judgment and probabilistic inference. In addition, troubleshooting is of great practical importance in numerous commercial and military systems, and it lends itself to economical implementation for training purposes.

Work to date has produced an operational system which demonstrates the feasibility of applying artificial intelligence techniques to computer-assisted instruction in a minicomputer-based training system. Experimental evaluations of ACTS have demonstrated that the adaptive decision model accurately learns the utilities of an expert technician and that students can effectively use the simulated troubleshooting task.

Additionally, instructions based on utilities can further improve the decision performance of students; however, feedback of optimum choices immediately following the student's choice also seems necessary.

2.2 Background: CAI and Decision Making

2.2.1 Individualized Instruction. A central theme in the field of educational technology is the creation of methods which allow individualized instruction. Training specialists and educational theorists recognize the importance of focusing on the individual student if significant advances in the efficiency and effectiveness of instruction are to be made (Crawford and Ragsdale, 1969; Glaser, 1965). Bloom (1968) has advocated the concept of mastery learning, in which instruction is de-

signed and managed so that all students reach a given level of achievement, albeit at different rates.

The principles now included under the rubric of programmed instruction (PI), which grew out of pioneering work by Pressey, Skinner, and others, have facilitated the practical implementation of mastery learning techniques. Such principles, also claimed as advantages of PI, include: student-paced progression, immediate knowledge-of-results, individualized instructional sequencing, use of explicit performance objectives, diagnostic assessment, and the division of instruction into small discrete steps. These principles formed the basis for the multiplicity of programmed textbooks, teaching machines, and the early CAI systems seen in the 1960's.

2.2.2 Adaptive Instruction. It has been recognized for more than a decade that true individualized instruction must include some form of adaptation to the individual student (Smallwood, 1962). However, while most researchers recognize the need to adapt instruction to individual differences, adaptation is usually made on the basis of response history. That is, the great majority of adaptive programs are made adaptive by the logic branching structure of the programs.

Central to the problem of adaptive CAI is the utilization of suitable criteria for optimizing learning effectiveness and the construction of decision rules for selecting instructional options. The development of adequate decision rules is very difficult in conventional adaptive CAI systems because a student's knowledge and skill level appears to be structured and fallible, when viewed in the context of CAI.

Sophisticated optimization techniques for maximizing learning effectiveness have been used in several very elegant and highly adaptive CAI programs (Atkinson, 1972; Smallwood, 1971). However, these techniques have

only been used for simple learning situations, which usually involve lower-order cognitive skills such as memorizing lists of vocabulary words. This is because the optimization methods (developed from control theory) require a precisely stated learning model which predicts student response to alternate instructional options. As skills become more complex, it is less likely that simple mathematical learning models can be found.

A promising approach to adaptive CAI is the application of Artificial Intelligence (AI) techniques. AI techniques and theory, traditionally, have been concerned with the intellectually demanding tasks of problem solving and goal-directed decision making. These techniques are uniquely suitable for applications where unstructured environments are involved (Nilsson, 1965; Slagle, 1971). Natural language understanding and the heuristic programming approach to pattern recognition have been used in CAI systems which are based on information structure representations of the subject matter (Carbonell, 1970; Hartley and Sleeman, 1973; Hoffman and Blount, 1974; Brown, Burton, and Bell, 1974). These systems utilize network analysis of the structures to generate instructional sequences, thus, the term "generative CAI."

Techniques of adaptive pattern classification can also be used to provide individualized instruction. Given a model of the student's behavior, the pattern classifier adaptively adjusts parameters of the model until the model accurately predicts the student's performance. The model parameters then provide the basis for generating instructions and feedback. For the present decision training system, the parameters of an adaptive decision model are used as the basis for training the student in a decision task.

2.2.3 Adaptive Decision Modeling. Adaptive models of decision making attempt to learn the decision process of the human operators by (1) successive observation of their actions, and (2) establishing an interim relation-

ship between the input data set and the output decisions (the model). Learning in this context refers to a training process for adjusting model parameters according to a criterion function. The object is to improve model performance as a function of experience or to match the model characteristics to that of the operator.

There are two areas of research which attempt to establish useful adaptive decision models. The first, derived from behavioral decision research, is termed bootstrapping (Dawes, 1970; Goldberg, 1970). This procedure uses a statistical regression process to fit the parameters of the decision model to the decision maker's previous judgments. However, the bootstrapping technique is applied off-line to decisions which have been observed earlier.

A second approach to adaptive decision modeling involves trainable decision and classification networks. This technique is used as the basis of the ACTS since it provides the capability to adjust model parameters on-line and to change model performance accordingly. Two types of models have been used in the ACTS, an Expected Utility Model (EU) and a Multi-Attribute Utility Model (MAU). The technique centers around adjustment of the EU or MAU model decision making. The decision network follows the decisions of the decision maker and adjusts its parameters to make it behave like the operator.

The dynamic value estimation technique, developed by Perceptronics in the context of a decision aiding task (Crooks, Kuppin and Freedy, 1977), is based on the principle of a trainable multi-category pattern classifier. The value estimator observes the operator's choices among R possible decision options available to him, viewing his decision making as a process of classifying patterns of event probabilities. The value estimator then attempts to classify the event probability patterns by means of an

expected utility evaluation, or discriminant functions. These classifications are compared with the operator's decisions and an adaptive error-correction training algorithm is used to adjust pattern weights, which correspond to utilities, whenever the classifications are incorrect. Thus, the utility estimator "tracks" the operator's decision making and "learns" his values.

2.2.4 Decision Models in Maintenance Training. A maintenance technician makes a number of decisions while servicing the systems under his responsibility. He must decide whether the system is performing within tolerable limits, what symptoms of trouble to consider, what information to gather in troubleshooting, what test equipment to use, and so on. For these types of decisions, the technician must be trained to know the alternatives available to him, to estimate the odds on the outcomes of these alternatives, and to assign a value to each alternative. For example, in auto maintenance, the mechanic is trained to adjust the distributor with a "feeler" guage or a dwell tachometer. He learns how accurately he is able to set the dwell angle with either instrument. The decision to choose one instrument or the other is influenced not only by the odds of setting the angle correctly, but also by the technician's stakes of values for each alternative. The feeler gauge may be preferred if it is right next to the mechanic in his tool box.

Decision training in maintenance should thus focus the student's attention on (1) listing the alternatives that he must consider, (2) estimating the odds of the various outcomes, and (3) evaluating the desirability of the outcomes. The adaptive MAU decision model in the ACTS provides a method for instructing the student in these activities. The student is not trained to make a specific sequence of decisions. Rather, the parameters of the MAU model are used as a standard reference to generate instructions about how to evaluate the decision alternatives. In the ACTS, adaptive

sequential decision training is implemented within the context of electronic circuit troubleshooting. The student's task is to find a circuit fault by making continued measurements until the device is repaired. However, the same principles can be applied to many other types of decision-making tasks.

The training given in the circuit fault diagnosis and repair task is based on the assumption that the student has a good basic background in electronics but that his experience with troubleshooting is limited. This might be the case with a student who has recently completed advanced military electronics training but has not yet performed troubleshooting tasks in his first permanent duty assignment. This skill level can be assessed either in terms of previous training received or in terms of performance on an entering test of electronics and troubleshooting knowledge. It is assumed that the prerequisite laws of electricity, circuit component behavior, circuit sub-systems, circuit diagrams, use of test equipment, and the like, have already been learned.

2.3 ACTS System Description

The ACTS is an interactive computer program that models and simulates the four functional units of training: (1) the task being trained, (2) the student, (3) the instructor, and (4) the instructional logic. The organization of these four units in ACTS is illustrated in Figure 2-1.

2.3.1 Task Simulator. In ACTS, the student's decision task involves troubleshooting an electronic device. The troubleshooting task centers on a model of an electronic circuit in which faults can be simulated. The circuits currently used are a modular version of the Heathkit IP-28 regulated power supply and the U.S. Army A9000 power supply. The simulated circuits have 10 and 11 functional modules, respectively, which can

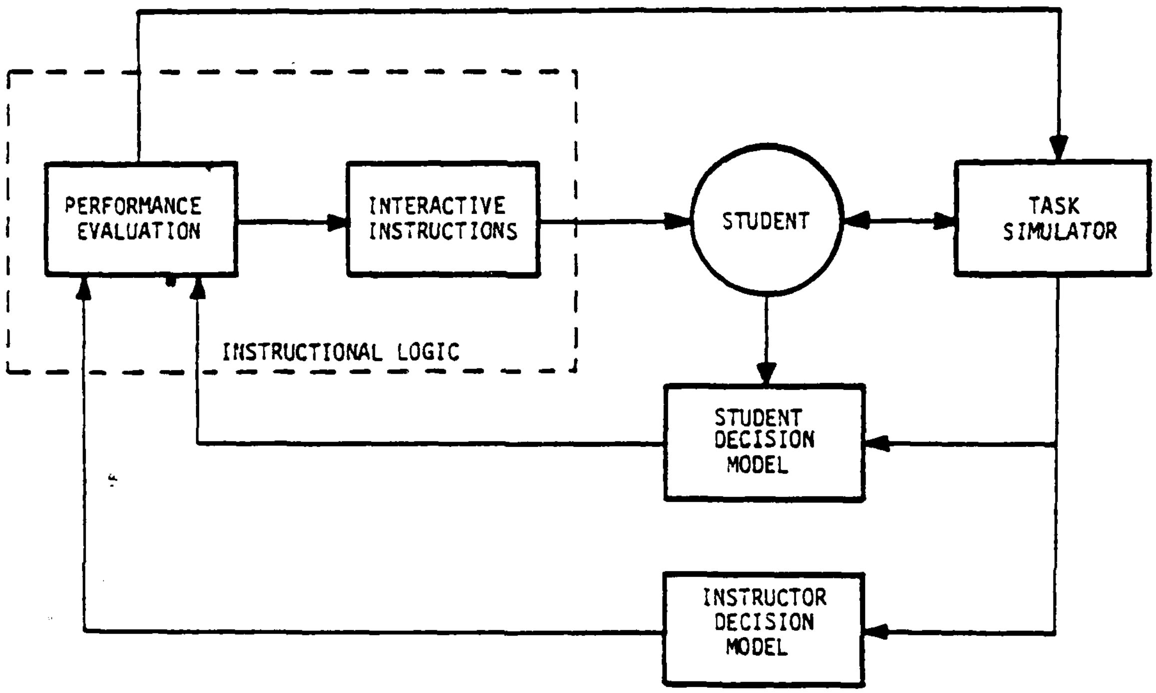

FIGURE 2-1.
ACTS FUNCTIONAL ORGANIZATION

be replaced and 32 and 23 measurements, respectively, which can be used to isolate faults. The operation of each power supply is simulated by the computer program, using a table-driven simulation of the fault system. The program simulates the results of checking symptoms, taking measurements, and replacing modules.

Training in the present system occurs with certain restrictions on the extent of circuit simulation. The student interacts with a terminal which contains a display of the simulated circuit; thus he cannot make such troubleshooting observations as smelling faulty capacitors, looking for burned resistors, or touching overheated semiconductors. In addition, the measurement results are presented in a semi-interpreted form (high, normal, low), rather than as absolute readings, (e.g., 3.6 volts, 1.25mA), so that the student need not refer to a table of normal circuit levels. Although these modifications involve an abstraction of the troubleshooting task, it is assumed that they do not affect the critical decision making aspects of the troubleshooting task.

The circuit simulation was designed to meet several objectives. In addition to providing an environment for observing troubleshooting behavior, the simulator gives the results of the student's choice of alternatives by displaying the results of measurements. Finally, the circuit model is designed to simulate the essential characteristics of decision-making under uncertainty. Thus, the outcomes of the measurements are probabilistic, reflecting the fact that, in practice, fault locations are uncertain for the troubleshooter.

2.3.2 Student Decision Model. The student decision model is a mathematical decision model used in the ACTS to model the decision behavior of the trainee and his instructor. The student decision model provides a method of describing or defining the student's behavior. The ACTS then uses the model to infer the current state of the student's knowledge.

The decision model not only describes the initial state of the student's knowledge but it also tracks changes in the student's performance, adapting the model parameters to describe the student's improvements and errors. From this model of the student's behavior, the ACTS gives instructions to improve the student's decision making.

A multi-attribute utility (MAU) decision model is used to represent the student. The MAU model is both a descriptive and normative model of decision making which assumes that a "rational" decision maker selects the alternative with the greatest expected value. The multi-attribute utility model is an improvement over the expected utility (EU) model that was the basis of decision models in the original system. This approach was selected on the basis of earlier experimental work done with the ACTS system. The MAU model has been applied to related areas in adaptive decision modeling and information acquisition tasks (Steeb, Chen, and Freedy, 1977; Samet, Weltman, and Davis, 1977) and was found to be more effective than the EU approach used in the original ACT system.

The improved MAU model has several advantages over the EU model: Fewer utilities are needed to model a particular circuit troubleshooting strategy; it converges faster, is more general, and is easily transferable across different circuits. It is also easier to establish a new model for different circuits and thus, it is more compatible with the operational training environment.

A unique aspect of the multi-attribute model is that utilities are assigned to general attributes of troubleshooting actions, rather than to specific outcomes only. According to the model, decision making within the context of electronic troubleshooting involves three basic factors: (1) Fault information gain, (2) commercial information gain, and (3) cost. The expected value of an action is then the sum of these

factors weighted by specific utilities. The attributes and model are presented below:

Fault Information Gain:

$$A_{i1} = \sum Pij\ (F-Fij)/F$$

Commercial Information Gain:

$$A_{i2} = \sum Pij\ (M-Mij)/M$$

Cost:

$$A_{i3} = C_i$$

MAU:

$$MAU_i = \sum U_K A_{iK}$$

Where

- Pij = Probability that the j'th outcome will occur if the i'th alternative is chosen.
- F = Current number of possible faults.
- M = Current number of possible faulty modules.
- Fij = Number of possible faults given current possible faults and the j'th outcome for action i.
- Mij = Number of possible faulty modules given current possible faults and the j'th outcome for action i.
- C_i = Cost of i'th action.
- A_{iK} = k'th attribute for action i.
- U_K = Utility for k'th attribute.
- MAU_i = Expected utility of action i.

Given the available alternatives, attribute levels and utilities, the optimum choice is determined according to the maximum expected utility

principle by calculating the expected utility for each possible alternative and then selecting that alternative with the greatest MAU.

ACTS uses the MAU model not only as the description of the student's decision making but also as the basis for estimating changes in his knowledge as inferred from his decision behavior. A technique of artificial intelligence, known as the learning network approach to pattern classification, is used to estimate the student's utilities in the EU model (Crooks, Kuppin and Freedy, 1977). The utility estimator observes the student's choices among the possible decision alternatives, viewing his decision making as a process of classifying patterns of event probabilities. The utility estimator then attempts to classify the event probability patterns by means of a multi-attribute discriminant function. These classifications are compared with the student's choices and an adaptive error-correction training algorithm is used to adjust pattern weights, which correspond to utilities, whenever the classifications are incorrect. This utility estimator operates concurrently in real time as the student performs troubleshooting operations; thus, the MAU model continuously tracks the student's decision performance as it changes during the course of training.

2.3.3 <u>Instructor Decision Model</u>. The second decision model in ACTS is an MAU model of an expert decision maker's performance. This model is used (1) as a standard against which the utilities of the student model are compared, and (2) as a source of help in directing the student's activities and in suggesting alternatives. The instructor model has the same mathematical form as the student model, except that the utilities are preset and remain constant throughout a session. The utilities of this model are adaptively estimated prior to the training session by tracking the performance of an expert technician as he indicates simulated faults or they are set based on *a priori* expectations of expert troubleshooting behavior.

The ACTS includes an algorithm for calculating the conditional probabilities of action outcomes. Conditional probabilities are of the form:

> The probability of obtaining a particular measurement outcome, given the previous measurement outcome history, and the measurement.

These conditional probabilities are obtained by the ACTS algorithm from the *a priori* fault probabilities, PK, by the following formula:

$$P_{ij} = \sum_{K \epsilon Oij} PK \qquad \sum_{K \epsilon S} PK$$

Where S is the current set of faults, Oij is the subset of S for which the outcome of action i is the j'th outcome. The *a priori* probabilities are obtained from an expert technician during the development of the task fault model.

2.3.4 Instructional Logic. The fourth major functional unit of the ACTS computer program is the instructional logic which selects the instruction and aiding information for the student. The instructional logic checks for convergence of the student's utilities, compares the student's utilities with those of the expert, and compares the student's expended cost with that of the expert for the same problem. These three condition checks are then used to select or modify the following messages:

> Your choices indicate that you are inconsistent in your troubleshooting strategy. Before making a choice, consider carefully the uncertainty reduction, fault isolation, and costs associated with each choice.

> Congratulations. Your choices show that you are consistent in your strategy for troubleshooting. However, there may still be differences between your strategy and the expert's. If so, the next page will describe these differences.
>
> You appear to overemphasize: uncertainty reduction and underemphasize: cost.
>
> Congratulations. Your performance is identical to that of the expert. You are now a qualified troubleshooter on the IP28 circuit.
>
> Congratulations on repairing the circuit. Your total cost to debug the circuit was 190. The instructor's total cost would have been 120.

Prior to the troubleshooting session, the student is assumed to have completed the preliminary lessons on the power supply involved. Consequently, instructions in the troubleshooting unit are not focused on the type of measurements to make or the functions of specific components or subcircuits. Rather, ACTS instruction is directed toward training an inexperienced technician to evaluate the utilities of the alternative measurements he can make and to select those alternatives that are most effective, given their relative costs.

In addition to the instructions that are displayed on the basis of the student's decision performance, the ACT system also includes a HELP option which the student can select as desired. The HELP option uses the expert decision model to suggest which measurements to make, their tradeoffs, and their relative overall values.

2.4 Hardware Configuration[1]

The hardware configuration for the ACTS is shown in Figure 2-2. It consists of four major components, namely an Interdata 70 minicomputer with a 64K memory, a Tektronix 4024 CRT for each subject, a console communication device, and an experimenter communication device, which may be either a CRT or a teletype.

The experimenter communication device is distinct from the console communication device because the structure of DOS does not allow the return of status for a supervisor call (SVC) read proceed on the console device. It is necessary to have this status return after a carriage return is received so that the ACTS can be apprised of the completion of a command input, independently, for any of the subjects or for the experimenter.

The experimenter's communication device is used to enter control parameters and to terminate student sessions. The experimenter has control of the system, both prior to the start of a teaching session and during its performance. Prior to the start of a session, the experimenter may enter certain system parameters to indicate specific options which are to be included in the current session. These parameters and associated options are summarized in Table 2-1. Additionally, the experimenter may terminate a student at any point during the instructional program.

Some of the experimenter's options are self-explanatory; those that are not are listed below:

---

[1] Commercial designations are used only for precision of description. Their use does not constitute endorsement by the Department of the Army or the Army Research Institute.

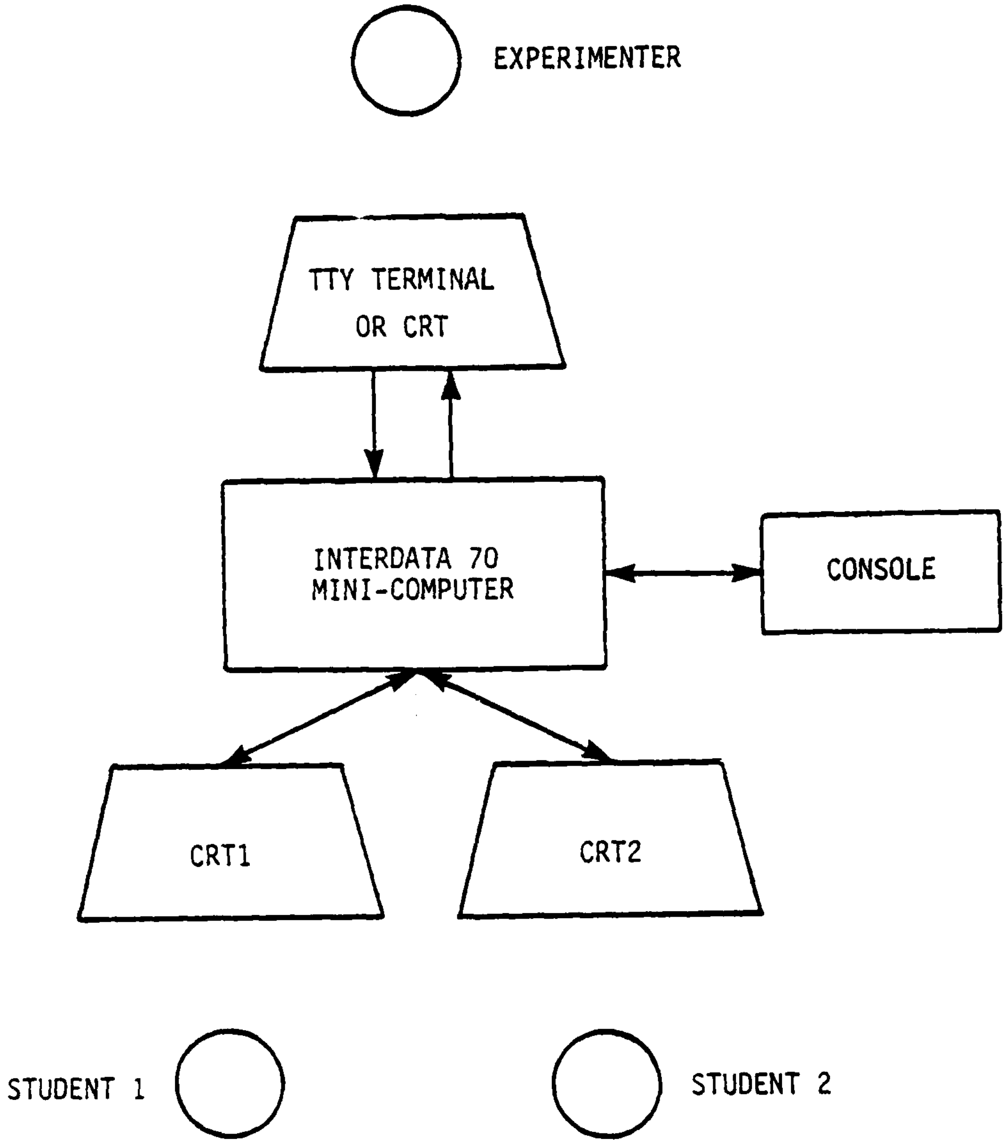

FIGURE 2-2.
MAN-MACHINE CONFIGURATION

TABLE 2-1

EXPERIMENTER-SUPPLIED SYSTEM OPTIONS

PARAMETERS	OPTIONS
I. Number of Students in Session	(1 or 2)
II. (For Each Student)	
1. Restart? (If restart, student's performance file is loaded from disk)	(1-Yes, 0-No)
2. Student's Name	Up to 20 characters
3. Current Date	Up to 20 characters
4. Circuit to be Used	(1 or 2)
5. Starting Objective	(2 or 3)
6. Starting MAU Model Weights for Student	3 values
7. Simulation	(1-gnome operator, 2-real student)
8. Simulated Subject Weights (Objective 3 only)	3 values to drive gnome operator
9. Help Available?	(1-Yes, 0-No)
10. Problem Presentation Sequence During Troubleshooting Objective	0 - Random 1 - Fixed

RESTART - If you wish to load the student's performance data from the disk and continue from the point that the previous session left off, the proper response here is "1" for "Yes." There is a single performance file available for storage on the disk; so, if you wish to pick up a session where it was terminated, no other student sessions may be run in the interim, since that would change the contents of the performance file.

CIRCUIT TO BE USED - The IP28 circuit is obtained by typing "1." The A9000 circuit is obtained by typing "2".

STARTING OBJECTIVE - The troubleshooting units for the IP28 are coded as unit "3." The single preliminary unit implemented for the IP28 is coded as unit "2."

STARTING MAU MODEL WEIGHTS FOR STUDENT - The student utility model must be given some set of starting weights. The weights are, respectively, for fault information gain, commercial information gain, and cost. Type in 3 integer values, each one followed by a carriage return. A good starting set of weights is: 1,1,1. The weights are normalized prior to MAU calculation.

SIMULATION - Currently no simulated subject has been implemented; consequently, the only legitimate response here is the "2" for "real student."

SIMULATED SUBJECT WEIGHTS - This option will not be presented since the simulated subject will not be selected for the simulation parameter.

HELP AVAILABLE - When a "1" for "Yes" is input at this point, all the keys from the expert model will be made available.

PROBLEM PRESENTATION SEQUENCE - The types of problem sequencing currently available are: random - problems are selected according to a uniformly distributed psuedo-random number sequence, and fixed - problems are presented in the order of the difficulty level of the corresponding fault.

> NOTE: In Table 2-1 the parameters 1, 6, 7, 8 and 10 provide information utilized in only the troubleshooting instructional unit. This unit is associated with objective XII in Table 2-2. However, the code for this unit used in the current implementation of ACTS is 3 as indicated in the prior discussion of starting objective. The reason for this is that only one of the preliminary units was implemented, namely the unit for objective II in Table 2-2, and a transition from this unit to the troubleshooting unit must take place by counting up 1 from the current unit.

If all students on the system during a session are terminated, the session will terminate. Each student has exclusive access to his or her own terminal, through which messages are sent or received.

Messages made available to the student are of two kinds: (1) strings of English language text, and (2) circuit diagrams or modifications to circuit diagrams (e.g., the brightening of a module to indicate that its replacement has been accomplished).

2.5 Instructional Approach

2.5.1 Training Procedure. Training on the ACTS is provided through a system of phased instructional presentations. A series of units on the given power supply is presented to the student. The material begins with the most basic information about power supplies and terminates with the

troubleshooting unit, which consists of a number of circuit fault problems. For all instruction prior to the troubleshooting unit, the procedure is to present text material to the student, allow him to ask questions and receive answers, and then give the student a test. If he passes the test he is advanced to the next unit; otherwise, he repeats the current unit. When the student has completed all the preliminary units, he begins the troubleshooting phase of instruction. Table 2-2 presents the instructional objectives for both the preliminary and troubleshooting phases of instruction.

Each troubleshooting problem consists of a single circuit fault which the student must locate and replace. On the display is shown a schematic diagram of an electronic circuit, plus printed messages which indicate possible actions and give information. The student selects his responses and types them in on a keyboard. The student can select from among a number of activities to isolate the fault in the displayed power supply circuit. The student can choose to take a voltage or current measurement, replace any circuit module, or request help. Following a student's command to perform these activities, the ACTS program displays the results of the simulated activity and then indicates the next allowable activities.

Interspersed among the fault problems, the ACTS presents the instructions which describe recommended circuit measurements and the conditions during which they should be chosen. After the instructions have been displayed, the fault problems are resumed. However, the student can request to see these instructions at the appropriate time by selecting the appropriate command on the display screen.

Appendix B presents samples of the instructional sequence which characterize the preliminary and troubleshooting phases of instruction.

TABLE 2-2

INSTRUCTIONAL PHASES WITH OBJECTIVES (IP28)

I. Given a description of a general power supply and the IP28, the student will state that the IP28 is a regulated power supply as opposed to an un-regulated power supply and specify the distinction.

II. Given an IP28 module and the macro-assembly of which it is a part, the student will correctly specify its function within the given macro-assembly.

III. Given any of the four operating conditions for the IP28, the student will specify which circuit modules are affected functionally by this condition and what the effect is.

IV. Given any module in the IP28, and a failure mode for that module, the student will correctly specify the functional consequences of that failure mode for a specified operating condition.

V. Given any module in the IP28 and a failure mode for that module, the student will correctly indicate the value of any voltage measurement anywhere in the system as high, low, normal, and unstable based on the circuit operating condition.

VI. Given initial circuit symptoms, the student shall report accurately one of the following:

(1) Circuit is functional and needs no adjustment.
(2) Circuit is malfunctioning.

TABLE 2-2 (CONTINUED)

VII. Given circuit symptoms with or without a history of pre-obtained measurement results, the student shall accurately select the most likely failure modes.

VIII. Given a set of possible failure modes, and a set of symptoms and measurement outcomes, the student will select those measurements most likely to test those failure modes within operationally defined tolerances based on the expert's MAU model.

IX. Given a set of measurements and module replacement candidates and a history of symptoms and measurement results, the student will rank them according to expected information gain, topological isolation potential, and cost.

X. Given the attribute levels for a series of measurements or module replacements the student will select a measurement or module replacement to perform differing from the expert's top MAU by a value less than some deviation tolerance.

XI. Given a symptom and measurement result history and the knowledge that one or more circuit modules has just been replaced, the student will make appropriate measurements to verify the result of the module replacements.

XII. The student will troubleshoot a non-functional circuit having one or two faults, replacing the failing modules in reverse order of dependency when malfunctions are causally related. Attribute levels will be displayed for him.

2.5.2 Consideration and Help. When the circuit is displayed, a malfunction is signaled by displaying overt symptoms in a table of symptoms and measurement outcomes. The student is then told that he will next be expected to input some action candidates for consideration. He may also ask for help at this point. Provided that the 'HELP' option is allowed, a help request will provide the student with the expert's considerations, as shown in Figure 2-3. After looking at these, the student may request help again--in which case certain tradeoff information for the expert's considerations will be displayed. This information includes the cost of each action, all outcomes and their probabilities for each action, and the fraction of faults to be eliminated by each outcome of each action.

The student next chooses his candidates for consideration. These candidates may be measurements and/or module replacements. The system then displays for him the value of each attribute for each of his considerations. At this point help may again be requested if the 'HELP' option is set to aid the student in choosing an action from amongst the considerations. The student may also choose immediately without help.

2.5.3 Action Selection and Help. If help is requested, the tradeoffs of the final considerations are then displayed. The message is the same as that used earlier to display the tradeoffs for the expert's considerations. Help may then be requested again, in which case, an expert ranking of the final considerations is presented. The attribute levels of the considerations are then re-displayed.

The student may then choose 'none of the above' in which case he will be asked for new considerations or he may type a choice from the list of considerations. If his choice is a measurement, its outcome is displayed in the symptom/outcome table. If his choice is to replace a module, the part of the display depicting the module is enhanced on the

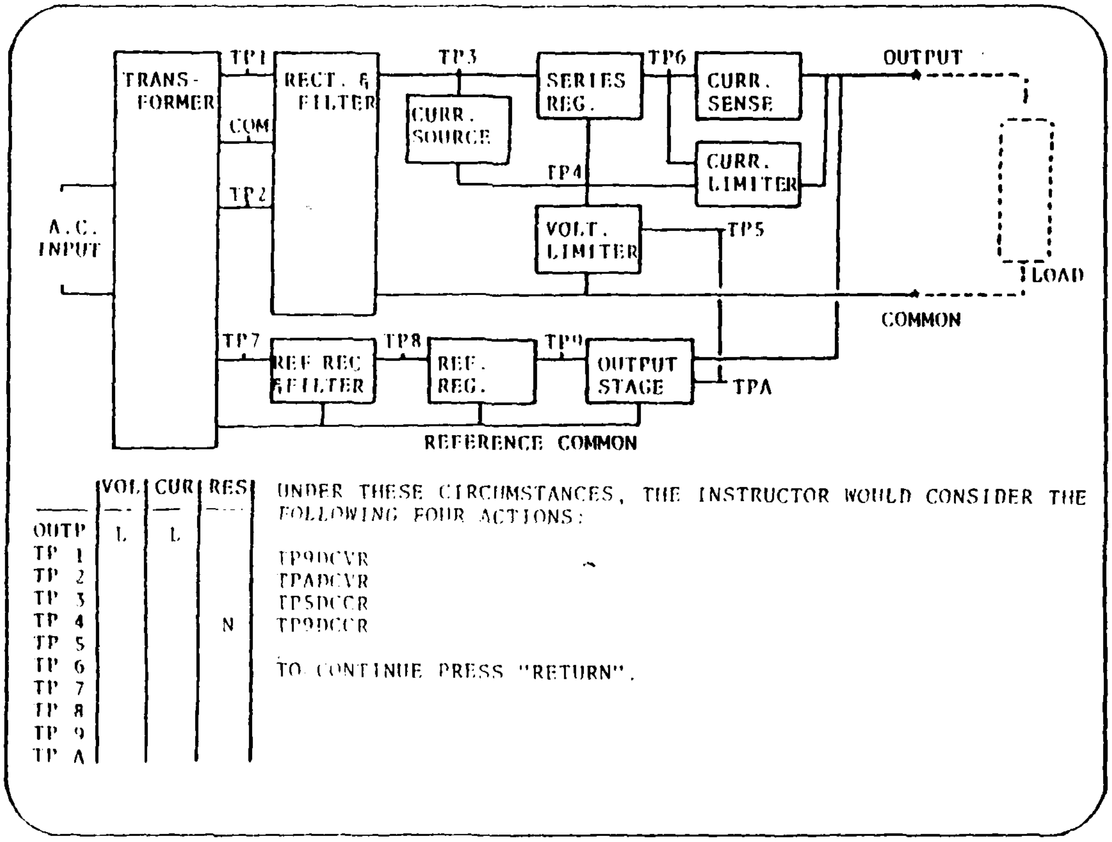

FIGURE 2-3.
EXPERT CONSIDERATIONS DISPLAYED
IN RESPONSE TO THE HELP OPTION

screen. If the chosen action did not repair the circuit, the cycle repeats with a request for new considerations. If the chosen action correctly replaced the faulty module, the overt malfunction symptoms are corrected on the screen and the system enters an evaluation phase.

2.5.4 Evaluation (Feedback) Phase. When the evaluation phase begins, the student is first congratulated on having repaired the circuit and given his total expenditure to compare with what it would have cost the expert. If his utility model has converged, indicating that he is using the displayed attribute information in a consistent manner, he is told that he is now consistent; otherwise, he is told to weight the attribute information more carefully. If his utilities differ significantly from the expert's, he is told which ones are high and which ones are low; otherwise, he is congratulated as an expert and instruction stops. Providing that he has not yet converged to the expert's utilities, the system advances to the next circuit fault problem and again presents malfunction symptoms.

2.6 Software

Two Perceptronics' documents are available which describe the ACTS software. The first, PFSS-1076-79-8, is a description of the software specification for the ACTS. The specifications are accurate for the configuration of the ACTS software as of the time the first experimental study was conducted. As a result of the study, some changes were made which will be described in Chapter 3, but the changes do not fundamentally alter the specifications as described in PFSS-1076-79-8. This document includes a description of the function as well as of the structure of the software, including the various files needed to run the system. Also, programs for instructional objectives are described.

The second document, PDCMDM-1076-79-7, is a manual for developing new circuit modules for the ACTS. Generalized techniques and step by step procedures are included to aid circuit model developers in creating instructional material, circuit-specific parameters, and software necessary to fully utilize the ACTS. The manual describes how a new circuit module is created and what instructional material is needed to familiarize the student with the characteristics of the specific electronic circuit. The circuit-specific parameters needed for implementing the new module in software are explained, as well as the steps necessary for integrating the new module with the rest of the system software. Procedures for creating circuit diagrams on the graphic display, representing circuit specific parameters in data tables, and procedures for generating circuit specific production rules are described in detail.

The manual emphasizes and describes the special considerations required for integrating the instructor's and the programmer's tasks when developing new circuit modules and associated lessons.

3. RESEARCH ISSUES

3.1 Objectives

Although the major objective of Year 1 was to develop and implement the software for the new ACTS as described in the previous section, an equally important consideration was to run a pilot study with actual subjects. The pilot study was needed to yield data concerning the subjects and the training potential of the ACTS. The pilot data were also used to test the system so that appropriate modifications could be made for the full-scale study designed for Year 2.

3.2 Subjects

Three students from the Electrical Engineering Department at California State University, Northridge, were recruited as subjects. The only recruiting requirements were that the subjects have Junior or Senior standing, or equivalent experience, and that they have a good working knowledge of English. The purposes of these requirements were, at first, to minimize the need for extensive preliminary training so that the subjects' time could be primarily devoted to obtaining data on the troubleshooting objective, and second, to avoid possible confounding effects due to difficulties in understanding the instructional text associated with the ACTS.

Some background information on the subjects was obtained by means of a preliminary questionnaire. The subjects were between 19 and 23 years of age, and they all had some experience in troubleshooting electronic circuits, as well as in interacting with computer-based systems. One female and two male subjects signed up for the experiment, which required two sessions, each lasting between 4 and 5 hours. They were paid at the

base rate of $5.00 per hour and, as an incentive, were told that they could earn additional pay for good performance at a rate of up to $4.00 an hour. Good performance was determined after the data were collected by comparing the three subjects' results with each other. The subjects were paid by mail, following the completion of their two sessions.

3.3 Instructions

When the subjects arrived for their first session, they were told that they were to participate in a study designed to train effective troubleshooting of an electronic circuit. They were seated at the console and were given a handout which contained an introduction to the task and to concepts relevant to power supplies in general, and to the IP28 in particular. In addition to this introduction, a troubleshooting guide was included in the handout in which measurement outcomes were defined; also a table of the probability of occurrence of module faults was given, as well as a table specifying the correspondence between faults and measurement outcomes. An additional table listed the responses recognized by the ACTS and their corresponding measurement or replacement costs. The handout is reproduced in Appendix A. The subjects in the present study felt that the handouts were quite clear, and they reported having no problems in understanding the concepts that were presented.

The subjects were run individually, with the experimenter sitting at a table nearby. After having read the handouts, the subjects completed the preliminary objective presented on the CRT, as discussed in the previous chapter. Any question was answered by paraphrasing the written instructions.

3.4 Sequencing

Currently, the sequence in which problems are presented to the student can be in one of two modes, random or fixed. The fixed sequence is a function of the level of difficulty of the problems, with easy problems being presented at the beginning of the instructional sequence and becoming increasingly more difficult as the sequence progresses. The major criterion for determining the level of difficulty of a problem was the logical complexity required for solving it. The minimum number of measurements required for isolating a fault was not a criterion of difficulty. For example, the faults of problems #7 and #8 can both be isolated by understanding the relationships between the initial (given) symptoms and the functioning of the modules, but it is rated as medium in difficulty because it assumes a high level of understanding of the modular functioning and interactions within the circuit.

Level of difficulty was defined as follows:

(1) Easy problems--simple fault isolation.

(2) Medium problems--fault isolation requires sequencing of measurements and understanding of modular functioning and interactions within the circuit.

(3) Difficult problems--fault isolation is in a feedback loop, requiring multiple measurements and a high level of understanding of the circuit action.

The problem numbers, which were not shown to the subjects, reflect increasing levels of difficulty, as defined above. Thus, for the fixed sequence, subjects were given problems #1 through #14 sequentially; for

the random sequence, the problems were simply selected randomly. In the present study, the random sequence was preprogrammed and was not randomized anew for each subject; this was a temporary simplification that will be changed for the Year 2 study.

3.5 Results and Analysis

During the troubleshooting part of the study, the students were allowed to refer to the tables in the handout which provided information concerning the types of measurements that are permissible and the characteristic outcomes for any given fault.

The students' responses were collected and printed out at the end of each problem. In addition, the experimenter noted the number of times the student asked for help and the amount of time needed to solve each problem. Information concerning the attribute levels of the students' considerations was also recorded by the experimenter.

During the first session, two of the students were given the fixed presentation sequence, and one student the random presentation sequence. This order was reversed for the second session.

3.5.1 General Results. Table 3-1 summarizes the data on several performance measures. The subjects' performances are reported individually for Sessions 1 and 2. The presentation order of the problems can be inferred from the problem number: consecutive problem numbers represent the fixed sequence, and non-consecutive problem numbers the random sequence.

The first column of Table 3-1 identifies the subject, the session (1 or 2) and the problem number. Columns 2 through 6 represent summarized in-

TABLE 3-1

SUMMARY OF SUBJECTS' PERFORMANCE

SUBJECT #	PROBLEM NUMBER	NUMBER OF MEASUREMENT DIFFERENCES[1]	NUMBER HELPS	UTILITY DIFFERENCES[2]	COST DIFFERENCES	TIME (MIN)	COMMENTS
1 SES #1	10	+1	9	.48	0	45	
	4	+2	7	.17	+12	45	CONVERGED
	11	0	0	.17	0	20	
	13	0	0	.13	-2	15	
SES #2	1	0	0	.17	+4	27	
	2	-1	0	.15	-10	12	CONVERGED
	3	0	0	.15	0	15	
2 SES #1	1	+1	22	.47	+70	120	
	2	0	20	.47	-2	45	MAXIMUM
	3	0	17	.47	+4	45	TIME
SES #2	10	0	2	.47	0	9	
	4	+1	5	.17	+8	13	SYSTEM
	11	-1	1	.47	-8	4	WENT DOWN
	13	0	4	.47	98	14	
3 SES #1	1	+1	12	.47	+70	90	
	2	-1	8	.47	-6	25	
	3	0	3	.36	+4	12	MAXIMUM
	4	+1	4	.36	+8	8	TIME
	5	+3	2	.27	+12	10	
	6	0	4	.27	0	10	
	7	0	4	.51	0	7	
SES #2	10	0	3	.47	0	16	
	4	+4	2	.26	+30	21	CONVERGED
	11	2	1	.26	0	6	
	13	0	1	.14	-2	23	
	10	0	0	.13	0	5	

[1] DIFFERENCES BETWEEN EXPERT AND STUDENTS

[2] MEAN OF ABSOLUTE VALUES FOR 3 ATTRIBUTES

formation on each subject's performance. The last column is used for comments. "Converged" means that the subject's utilities came to match those of the expert within a certain tolerance limit. In the present study, convergence automatically stopped the session because the subject was assumed to have become an expert. Subject 1 converged in both sessions and Subject 3 converged in the second session. "Maximum time" means that the session was ended because the 5 hours allotted to it were used up. This happened for both Subjects 2 and 3 in the first session. During the second session with Subject 2, the system went down and the session was ended for that reason.

3.5.2 Expert's Model. Of the five performance measures reported, three of them represent comparisons between the subject's performance and that of the expert. The expert's performance--namely the sequence of measurements and module replacements--was determined theoretically by applying the expert's model to the attributes under consideration, namely the reduction in uncertainty, the expected fault isolation, and the cost of the action. Initially, the utility levels for the expert were set in such a way that the attribute of cost was given a slightly higher weight than the other two attributes, decrease in uncertainty and fault isolation. Given these assigned attribute weights, the expert's model was simply applied to the system to determine the best action sequence for each fault. This sequence is shown in Table 3-2 for each fault. The number of the fault corresponds to the fault numbers identified with the ACTS programs: they are only used for identification and were not shown to the subjects. The sequences of measurements and module replacements shown in Table 3-2 represent the best expected performance in the long run, although they may not be optimal for any particular fault. That is, in any particular case, it is possible for a subject to isolate a fault more cheaply than the expert, or by using fewer measurements,

TABLE 3-2

OPTIMAL DECISION SEQUENCES (EXPERT)

FAULT	COST	SEQUENCE				
1	120	TP4REPO	TP9DCVR	TP3ACVR	TP1ACVR	TRA
2	92	TP4REPO	TP9DCVR	TP3ACVR	TP1ACVR	REC
3	116	TP4REPO	TP9DCVR	TP3ACVR	TP4DCVR	SOU
4	90	TP4REPO	VOL			
5	90	TP4REPO	LIM			
6	58	TP5DCVR	STA			
7	50	SEN				
8	130	SEN	LIM			
9	116	TP4REPO	TP9DCVR	TP3ACVR	TP4DCVR	SER
10	88	TP5DCVR	VOL			
11	58	TP5DCVR	STA			
12	88	TP4REPO	TP9DCVR	TP8DCVR	REG	
13	88	TP4REPO	TP9DCVR	TP8DCVR	REF	
14	186	TP4REPO	TP9DCVR	TP8DCVR	REF	TRA

TABLE 3-2 (CONTINUED)

EXPLANATION OF ACTION CODES:

Any three letter sequence corresponds to a module replacement. The full meanings of each module replacement abbreviation are given below:

TRA - Transformer
REC - Rectifier
SOU - Current Source
SER - Series Regulator
SEN - Current Sense
LIM - Current Limiter
VOL - Voltage Limiter
REF - Reference Rectifier and Filter
REG - Reference Regulator
STA - Output Stage

(See A-12, Figure 2)

The seven letter strings refer to measurements. The first three characters refer to the major test point (See A-12, Figure 2). The next two characters can be any of the following possibilities:

AC - Alternating Current
DC - Direct Current
RE - Resistance

The final two characters can be any of the following possibilities:

VR - Voltage Regulated
CR - Current Regulated
PO - Power Off

Thus, TP4REPO means a measurement with major test point 4, resistance check, in power off mode.

but in the long run, based on the multi-attribute utility model, the expert's model optimizes all troubleshooting sequences.

3.5.3 Number of Measurements. As can be seen from Table 3-2, the optimum number of measurements required to isolate a fault varies widely across problems. In some cases, a fault can be isolated in a single measurement, while in others, as many as five measurements are needed minimally. It would be meaningless, therefore, to list the number of measurements made by each subject on a given problem; rather, the performance measure reflects the difference between the number of measurements made by the subject and the optimum number suggested by the expert's model.

The difference between the subjects' and the expert's number of measurements is shown in column 2 of Table 3-1. Positive numbers mean that the subject made more measurements than the expert, zero means that the number of measurements was the same (but not necessarily that the measurements themselves were identical), and negative numbers mean that the subjects found a solution requiring fewer measurements than the expert's model. In this case, while the subject's solution may appear more efficient, it does not imply that such a solution follows the rules of optimal decision making.

3.5.4 Help Option. The help option provides the expert's considerations for any given action and ranks those considerations from best to worst, based on the multi-attribute utility model. By continually using the help option, therefore, a subject could conceivably isolate a fault and replace the correct module in the most efficient manner without learning the decision-making procedures inherent in the ACTS. According to the built-in criteria, a subject could then become an expert at troubleshooting electronic circuits simply by following the expert's

considerations, unless the subject's utilities are differentially trained as a function of using help. Thus, whenever help is used, the training of the subject's model is deactivated, implying that the subject's performance does not reflect any learning.

As discussed in the previous chapter, help could be obtained at several points in the course of isolating a fault. For each problem solved, the experimenter counted the number of times the help option was used by the subjects, and this count is reported in column 3 of Table 3-1. The number of times help was used varies a great deal over subjects, but it does seem to reflect some learning in that the amount of help used decreases over trials for all subjects. This may be a result of a decrease in need for help, but it may also be a function of the instructions. Although the subjects were urged to use the help option whenever necessary, the instructions did specify that help should be used as little as possible so that their performance would reflect the course of learning the decision-making procedures of the ACTS.

The data also reflect a certain correspondence between the amount of help used and the difficulty each subject experienced with the system. Subject 1, who converged rapidly in both sessions, only used the help option for the first two problems, while Subjects 2 and 3 used it throughout the first session. In all cases, the amount of help used during the second session was noticeably less than during the first session. An additional reason for the decrease in the use of help is that the handout provided the subjects with sufficient information for them to make reasonable selections without the use of help. That is, the tables gave them all the options necessary to effectively troubleshoot the circuit.

3.5.5 Utility Differences. Changes over time in the differences between the subjects' utilities and those of the expert reflect the adaptation of the subjects' behavior to correspond more closely to that of the expert. This comes about as a result of the feedback provided at the end of each problem which informs the subjects when they appear to weigh one or another of the attributes too heavily or too little. Changing their behavior in response to this feedback causes their utilities to gradually match those of the expert, producing convergence of the two models.

The differences between the subjects' utilities and those of the expert are shown in column 4 of Table 3-1 and in Figures 3-1 to 3-4. Column 4 of Table 3-1 and Figure 3-1 show the mean of those differences, while Figures 3-2 to 3-4 show the changes in the utility differences for the individual attributes. Since some of the utilities are negative, the mean was calculated by taking the absolute differences between subjects and experts.

The utility differences on individual attributes appear almost erratic from problem to problem, but when the mean of the differences is used, the progression of the subjects' behavior is more apparent.

Although all performance measures suggest that some learning is taking place, utility differences probably reflect convergence of the two models, and hence learning, better than any of the other performance measures. This learning is readily reflected in Figure 3-1.

From both sets of data, the individual and the mean differences, it is clear that Subject 1 became very rapidly familiar with the system, a result which is also reflected in the amount of help used and the time taken per problem. A similar result was obtained for Subject 3: all

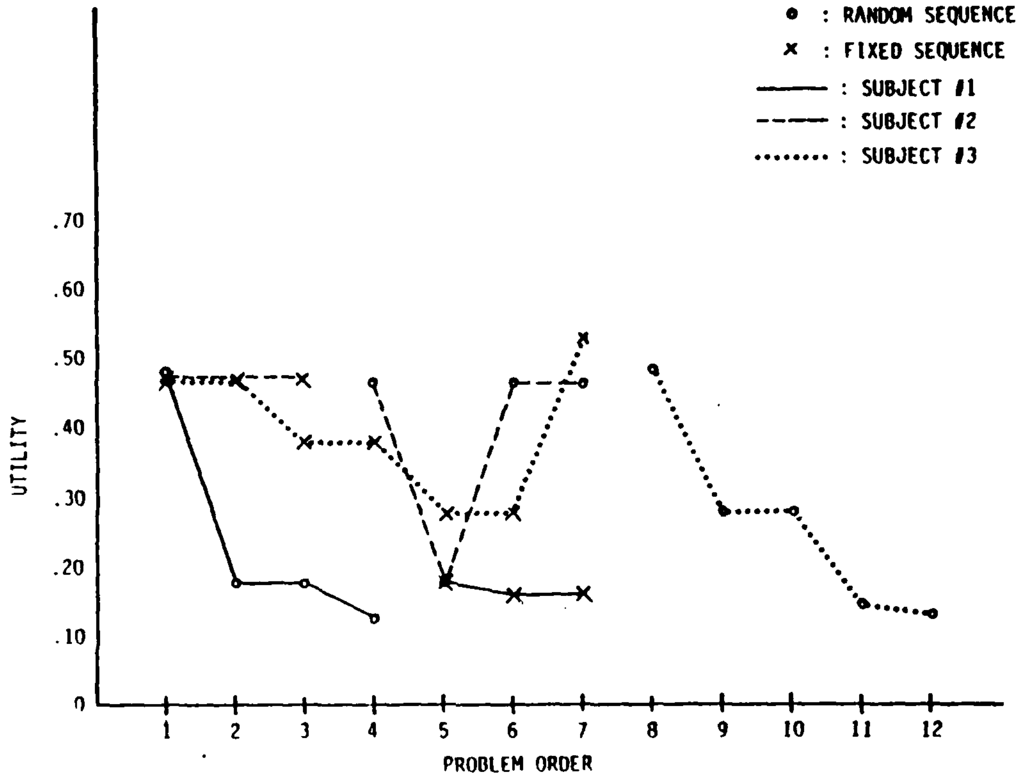

FIGURE 3-1.
MEAN OF ABSOLUTE UTILITY DIFFERENCES

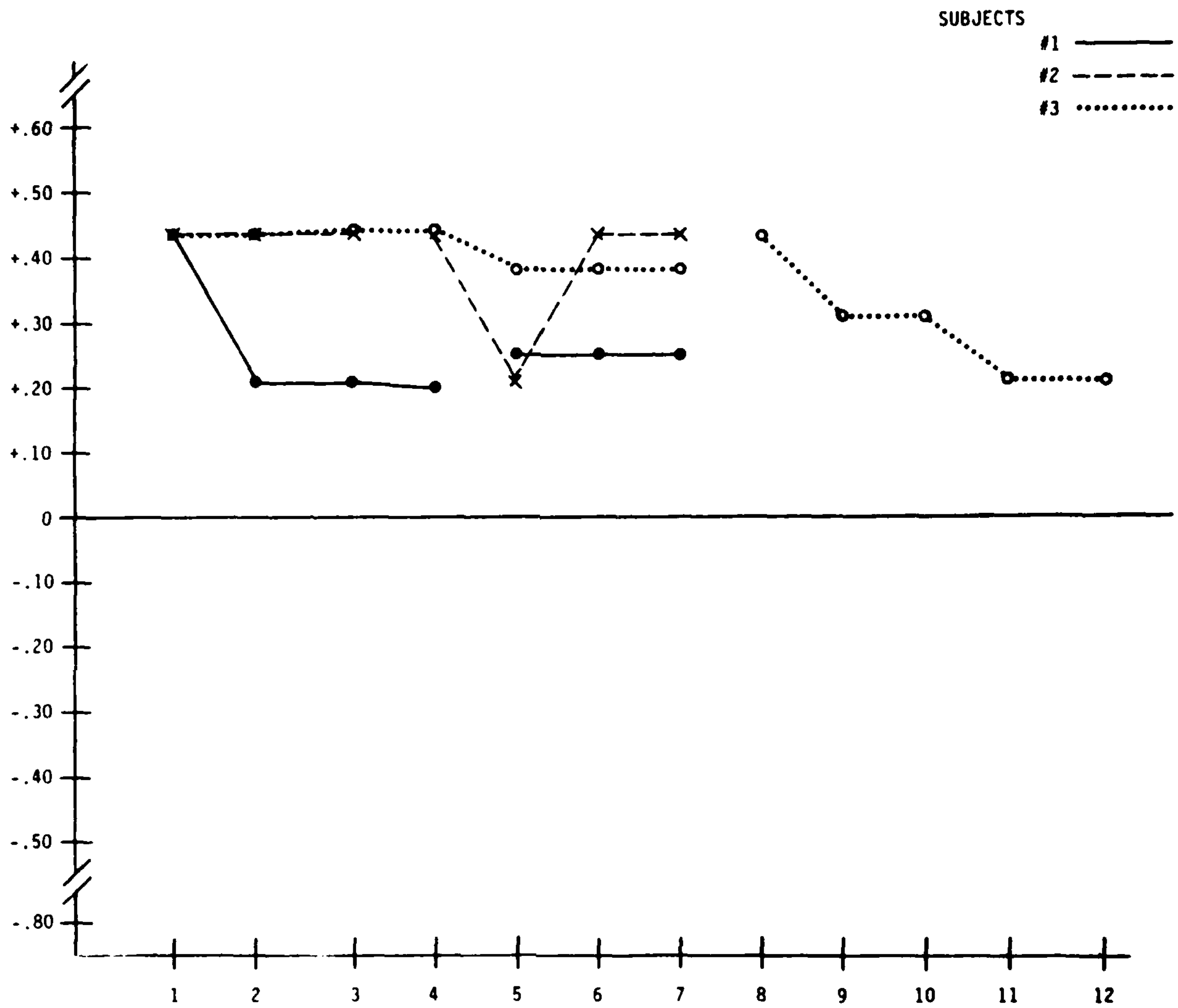

FIGURE 3-2.
UTILITY DIFFERENCES FOR UNCERTAINTY REDUCTION

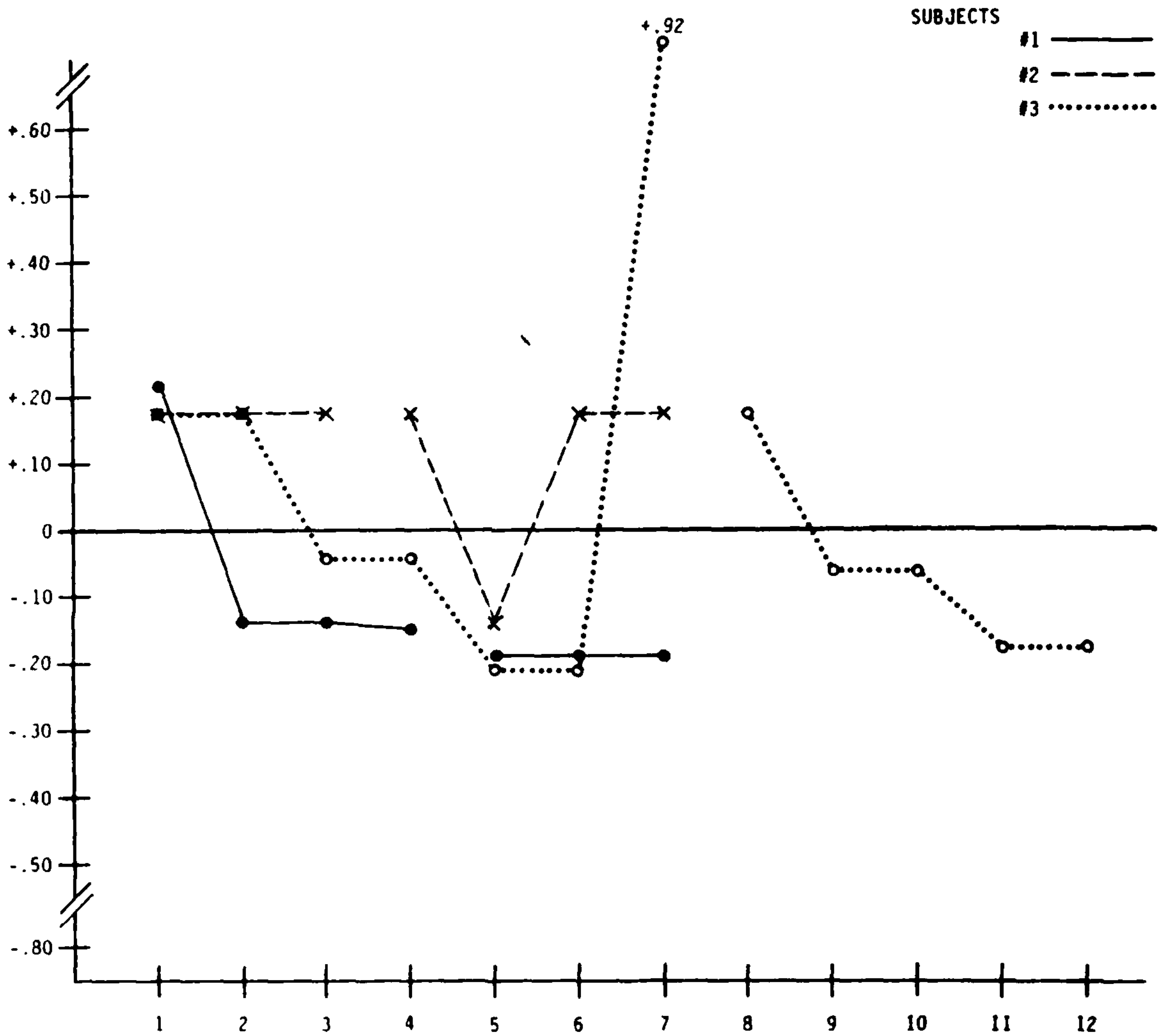

FIGURE 3-3.
UTILITY DIFFERENCES FOR FAULT ISOLATION

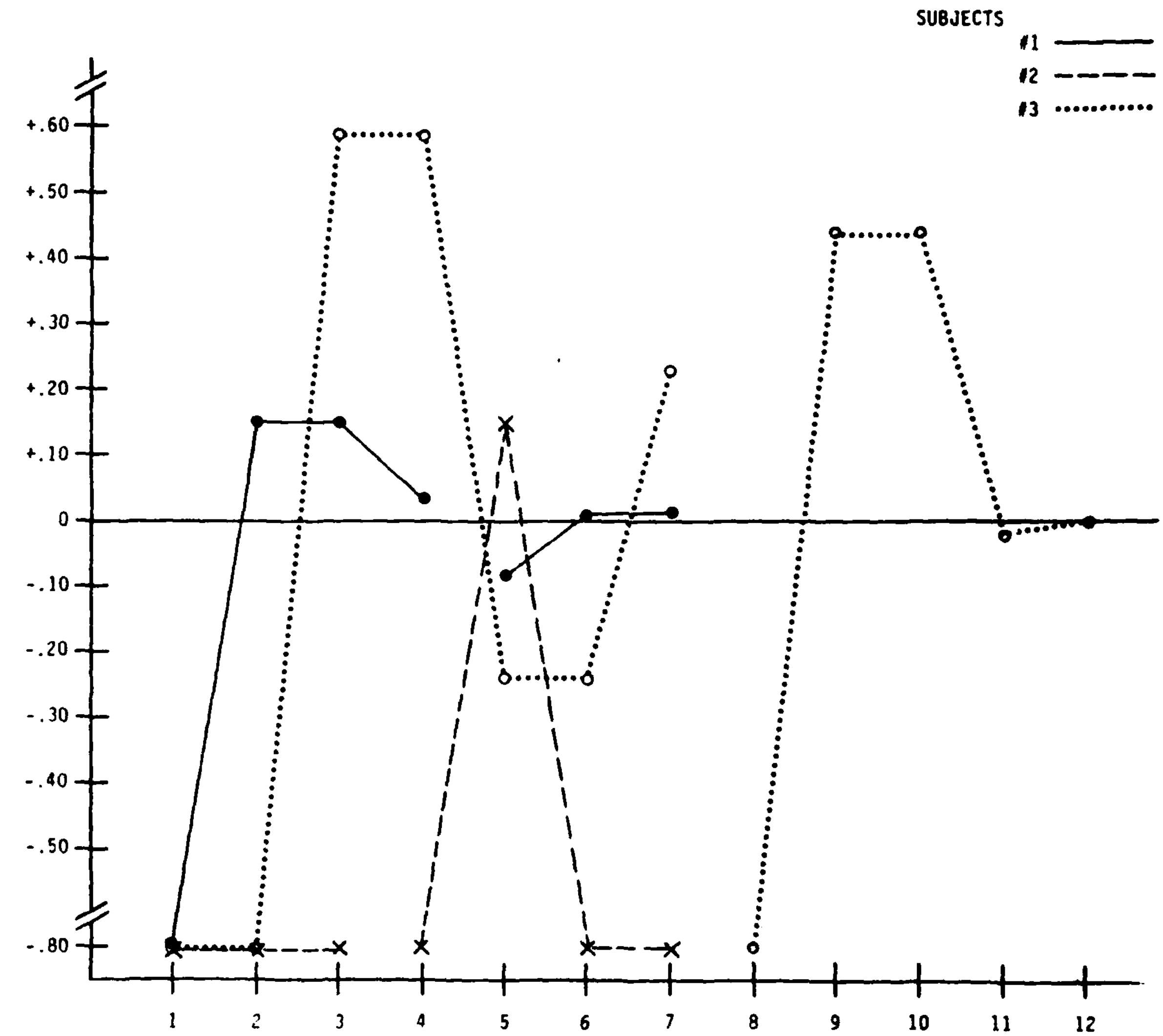

FIGURE 3-4.
UTILITY DIFFERENCES FOR COST

performance measures improved over time, even during the first session, including his decision-making performance, even though he only converged during the second session.

While convergence of the utilities appears to be reflected in similar improvements on the other measures, the obverse is not necessarily true. Improvements can be observed on some measures without coresponding convergence of the utilities. For example, the amount of help used and the time taken per problem did improve over trials for Subject 2, but his utilities remained quite stable across all problems, suggesting that this subject was not learning to match the expert's model and that he was not making effective decisions.

The above seems to suggest that several types of learning take place during an ACTS session, a consideration which will be further investigated in Year 2.

Decreases in utility differences mean that subjects are learning to troubleshoot the circuit efficiently with respect to their decision-making behavior, and are correlated with the concept of convergence. For Subject 1, the mean difference drops below .20 on the second problem already and remains there for all the other problems; thus, Subject 1 converged to the expert's model almost immediately, matching her decision behavior to that of the expert. It is equally clear from Figure 3-1 that Subject 2 did not converge: the mean difference dropped once to less than .20, but then increased again; Subject 2 therefore, did not learn the appropriate decision behavior. The curve for Subject 3 appears to tend towards convergence in the first session, but then the difference increases again on problem 7; during the second session, on the other hand, the mean utility difference decreases steadily, and subject 3 did achieve convergence.

3.5.6 Time Per Problem. Of the five hours allotted to each session, approximately one hour was used up for the instruction and the preliminary objective. Even though there is a real time clock associated with the Interdata 70, software considerations, mostly a lack of sufficient computer memory, precluded the use of it. As mentioned, therefore, the experimenter clocked the amount of time needed for each problem. This provides a perfectly adequate measure, given the range of times needed to isolate a fault.

Time per problem varied widely across subjects, but decreased dramatically over problems for all subjects, the greatest decrease being observed between the first and second problem. A decrease over the two sessions is also clearly evident, as shown in column 6 of Table 3-1 and in Table 3-3 which gives the mean time per problem in the two sessions for each subject. The actual number of minutes spent on each problem is shown in Figure 3-5 for each subject. The two sessions are indicated by a break in the curves for each subject. Since the number of problems solved varied across subjects, the breaks do not occur at the same place for each subject.

Figure 3-5 clearly shows the sharp decrease in the amount of time needed per problem, especially over the first two problems for Subjects 1 and 3. Subject 2 required so much time for each problem in Session 1 that he was only able to solve three problems in the allotted time (approximately four hours). However, much saving can be observed at the beginning of Session 2 (from 45 minutes to 10 minutes).

These decreases in time and savings over the two sessions are primarily attributable to increases in familiarity with the system, including the consoles, the types of allowable measurements, and the responses to be made. This is evident from the sharp drop observed after problem 1. It

TABLE 3-3

AVERAGE TIME PER PROBLEM

SUBJECT NUMBER	SESSION 1	NUMBER OF PROBLEMS SOLVED	SESSION 2	NUMBER OF PROBLEMS SOLVED
1	27 min	4	15 min	3
2	70 min	3	10 min	4
3	23 min	7	14 min	5

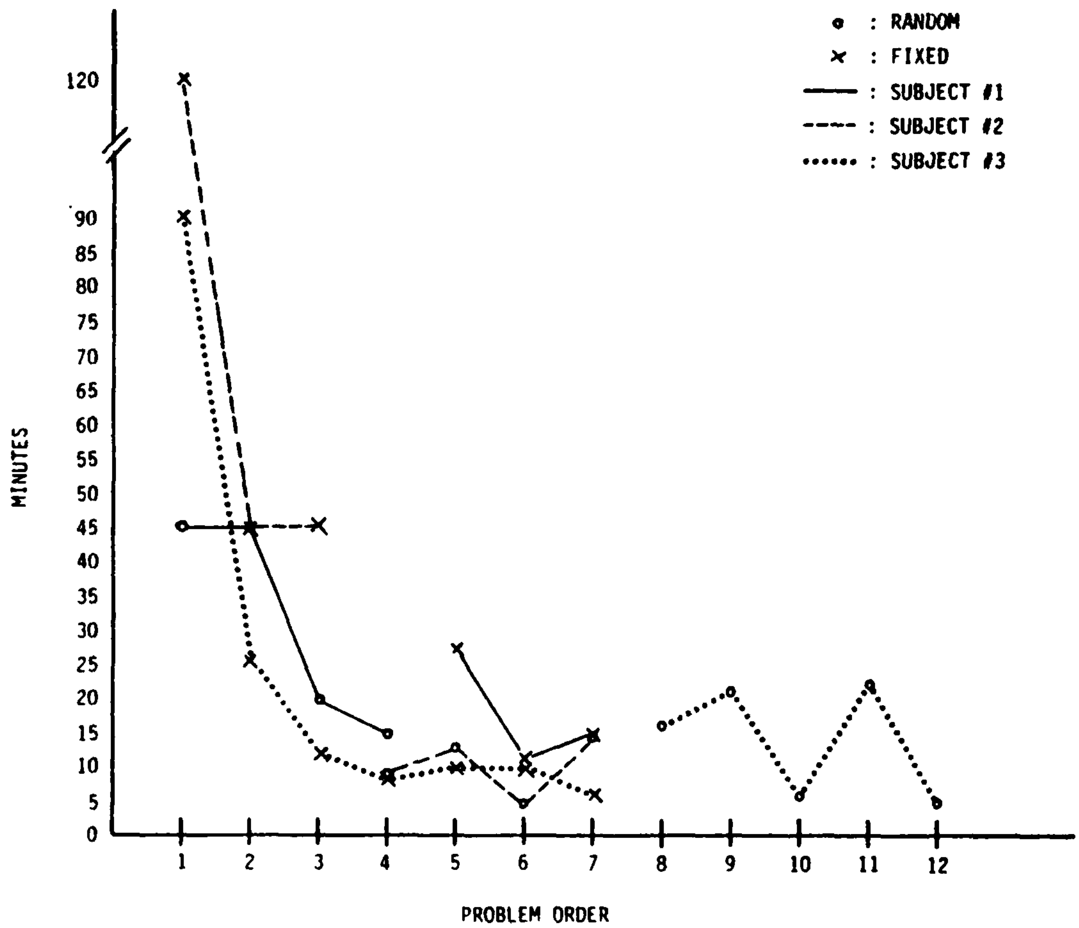

FIGURE 3-5.
NUMBER OF MINUTES SPENT ON EACH PROBLEM

is not attributable to the difficulty level of the problems, since the difficulty level for Subjects 2 and 3 increased over time, and was random for Subject 1. It is clear that for the Year 2 study, a few problems must be presented to all subjects to familiarize them with the operation of the system if meaningful evaluations are to be obtained from the various experimental groups.

Number of Problems Solved. Column 7 of Table 3-1 gives the number of problems solved by each subject. As with the other measures, this varied a great deal over subjects. Two factors contributed to this. First, there was a time limitation as discussed earlier. Thus Subject 2, whose mean time for Session 1 was 70 minutes per problem, was only able to solve three problems during that time, in contrast to Subject 3 who solved seven problems. Second, the parameters of the program were such that when a subject's utilities converged - the subject was declared an expert, and the program stopped. This is what happened in the case of Subject 1 who learned very rapidly to make efficient and consistent decisions, and thus become an expert within a few trials.

Stopping the program when a subject becomes an expert may provide an efficient way of using the ACTS in an actual training situation. For experimental and evaluation purposes, however, it is necessary to have a great deal of data that are comparable across subjects. For this reason, this option will be changed in the Year 2 study. Even if subjects do become experts, they will continue to solve problems until the number of problems specified in the experimental design have been run.

3.5.7 Debriefing Questionnaire. The subjects were given a debriefing questionnaire at the end of the first session, as shown in Table 3-4. In general, all subjects felt that they had learned to optimize the types of measurements to make in order to isolate the fault as effi-

TABLE 3-4

DEBRIEFING QUESTIONNAIRE

1. Do you feel you learned *anything*? _______ If so, what? __________

   ____

   ____

   If not, what would you have liked to learn? __________________

   ____

   ____

2. Were you confused about anything? _______ What? ______________

   ____

3. Did you find the "Help" option useful? ____________________

4. In general, did you agree with the expert's suggestions? __________

   ____

5. Would you have liked more help? _________________________

   If yes, for what actions? ____________________________

   ____

   ____

   In what format? ________________________________

   ____

   ____

6. Please make any comments or suggestions you feel may be appropriate.

   ____

   ____

   ____

   ____

   ____

We appreciate your contribution to, and participation in, this experiment. Thank you.

ciently as possible. However, all subjects also answered positively to Question #2, asking if they were confused about anything. One subject did not understand what the expert's choices were based on, another subject felt that the "computer was inconsistent with its input," and the third subject wondered about the purpose of the modules and their relationship to each other. They all felt the "Help" option was useful and, in general, agreed with the expert's choices. Only one subject (Subject 2) did not want help; the other two would have liked more help in understanding the information provided by the expert, perhaps in the form of an example in the handout, and an explanation of how the expert's choices were arrived at. These problems are the result of the abbreviated use of preliminary objectives and will be easily remedied in the future.

3.6 Discussion

3.6.1 Learning Effects. Overall, the results appear promising in terms of the training potential of the ACTS. A great deal of learning appears to have taken place on all performance measures and much of this learning transferred from one session to the next. This is encouraging, considering that the two sessions were separated by at least one week for all subjects. Even Subject 2, whose utilities did not converge to those of the expert, shows transfer of learning on the amount of help used and the time taken per problem. Subjects 1 and 3 exhibited learning and transfer on all performance measures.

From the figures, it is clear that a great deal of the learning occurs in the initial trials, and this is probably more likely to be related to the processes of familiarization with the equipment and the task, than to the acquisition of decision-making strategies. However, the figures also suggest that this familiarization process does not take more than

one or two trials. In order to eliminate these effects in the Year 2 study therefore, the first session will begin with the presentation of one or two randomly selected problems which will serve to familiarize the student with the mechanics of using the ACTS, the feedback format, and the various types of help.

3.6.2 Sequencing Effects. The question of different effects attributable to the sequencing of problems cannot be answered at this time, since the differences in the subjects' abilities were so large and so few subjects were available. Effects of sequencing will depend a great deal on the accuracy with which problem difficulty can be identified. From the results, it apears that some problems which were identified as somewhat difficult, were in fact easy for the subjects to solve. There are at least two confounding factors which impinge on the interpretation of the problem difficulty. One will be discussed below under "Use of Handout", the other is concerned with the level of the students' ability: for college-level students, having some background in electronics, problems identified as being of medium difficulty may in fact be as simple as the easy problems, since difficulty is related to the logical complexity in the circuit, and college students have had much practice in dealing with logical complexity. This may not be true for high school students who may have had less experience in dealing with logical complexity.

In order to avoid this problem in the Year 2 study, a base rate for problem difficulty will be established using performance on the random sequence. A problem's level of difficulty, therefore, will be empirically rather than logically determined. Although this violates the standard practice of random assignment of subjects to groups, the benefits of this approach outweigh the dangers of partially violating the random assignment directive.

3.6.3 Use of Handout. The first factor mentioned above, which would prevent evaluating sequence effects, has to do with the use of the handouts, and especially, the availability of Table 2 of this handout, showing the match between module faults and measurement set. This table shows exactly what types of measurements should be made, given different types of initial outcomes, so that a bright student can in fact use this table exclusively, without ever using the help option. All the students in the pilot study discovered this quite rapidly.

The use of such a handout is acceptable as a training device, but there are at least two considerations to keep in mind. The first is that the ACTS only incorporates single faults and the characteristic measurements obtained are fairly straight forward. In an actual troubleshooting environment, however, there is no guarantee that a faulty circuit will have a single fault; a breakdown could be the result of a combination of faulty modules. Obviously, in such a case, the measurements would not be as straightforward as those listed in Table 2 of the handout. Measurement outcomes in the ACTS are given as high, normal, low, or zero, but in an actual environment, the measurement outcomes are numbers which have to be evaluated. For example, an outcome that is slightly above normal could in fact be normal or high. This type of decision cannot be trained by the current version of the ACTS, and its possible effect in evaluating transfer to actual equipment will have to be kept in mind.

The second consideration in the use of handouts concerns the types of learning that can take place during an ACTS session. On the one hand, one may emphasize the cognitive aspects of training to troubleshoot a circuit. In this case, it is advisable to use as many cognitive aids (such as handouts and charts) as possible and to emphasize background knowledge. On the other hand, the ACTS can also be viewed as a more mechanistic training device where responses become differentially rein-

forced through a conditioning process. That is, it is quite conceivable that the appropriate responses, those which correctly utilize the attribute information provided, will become trained simply as a result of repeated trials with fairly immediate feedback. In this case, the use of cognitive aids would not be beneficial. Thus, whether handouts or other aids are used in conjunction with the ACTS must be determined in relation to the cognitive abilities of the students using the ACTS and to the training objectives of the school.

For the Year 2 study, a combination of these two extremes has been selected. The handout will be made available to the subjects during initial training, for approximately three problems, to give the subjects an opportunity to understand the relationship between measurements and module faults. Further training, however, will be done without the handout.

3.6.4 Sliding Window. Aside from the improvement already discussed, a change in the sliding window was made. The sliding window refers to the number of problems over which the training weights are calculated.

The sliding window of size N consists of training information for the last N choices selected by the student during decision cycles where help was not invoked. Decision cycles involving help disallow any student model training and thus are not involved in constructing the window. Two statistics are available from the window: (a) total number of times training occurred out of N, and (b) sum of the absolute values of all adjustments to the model for these N decisions.

In the pilot study, the sliding window parameter was 3, so that the utility weights were calculated for problems 1-3, 2-4, and so forth. This tends to produce very rapid convergence, with some probability of spurious results. It was therefore decided to make the sliding window dynamic,

which means that the parameter can be changed according to current needs. For demonstration purposes, for example, when rapid convergence is desirable, the size of the window can be made small, but during an experiment or for training, the parameter can be accordingly increased.

3.6.5 New Performance Report Printout. On the basis of the pilot studies performed, the performance report has been completely revised, primarily to obtain more detail of the subjects behavior. The new report is shown in Table 3-5. Table 3-6 explicates the report. For each action, the student's considerations, attribute levels and expert's choices will be printed out; the actual action selected and its outcome will be shown, as well as ongoing changes in the student's utilities. This differs from the pilot study in that information is obtained after each action, rather than just at the end of each problem. Overall, this report provides a performance record which traces every decision make by the ACTS student.

TABLE 3-5

PRINT-OUT REQUIREMENTS FOR
ACTS80 TROUBLESHOOTING OBJECTIVE

STUDENT: AGE: DATE:
CIRCUIT: FAULT:
HELP AVAILABLE: FEEDBACK AVAILABLE:
SLIDING WINDOW:

STUDENT INPUT SEQUENCE:

STUDENT'S CONSIDERATIONS	ATTRIBUTE LEVELS	EXPERT'S CHOICES (WHEN "HELP" IS USED)
____	____	____
____	____	____
____	____	____
____	____	____

ACTION SELECTED: UTILITY RATIOS:
ACTION OUTCOME: SLIDING WINDOW PERFORMANCE:
SUBSEQUENT UTILITIES: CLOSENESS TO EXPERT:
UTILITY DIFFERENCES: CONVERGENCE:

TYPE OF HELP:

(PRINT AFTER EACH ACTION)

STUDENT WEIGHTS:
STUDENT COST:
EXPERT COST:
TIME IN MINUTES:[1]
____[2]
____
____

[1]"TIME" TO BE FILLED OUT BY EXPERIMENTER

[2]EXTRA SPACE FOR OTHER COMMENTS

TABLE 3-6

REPORT CONTENT DEFINITION

The information content for each label in the ACTS80 Troubleshooting Printout is described below:

STUDENT	Student's name
AGE	Student's age
DATE	Date of experiment
CIRCUIT	1 - IP-28 power supply 2 - A9000 power supply
FAULT	Fault no. for current problem
HELP AVAILABLE	0 - no 1 - yes
FEEDBACK AVAILABLE	0 - no 1 - yes
SLIDING WINDOW	The no., n, of most recent action choices used to check for consistency in student model
STUDENT'S CONSIDERATIONS	The names of the actions that the student considered
ATTRIBUTE LEVELS	The attribute levels for the student's considerations
EXPERT'S CHOICES	The expert's considerations by name
ACTION SELECTED	The name of the action chosen by the student
ACTION OUTCOME	The outcome of the action performed (e.g., "L" for low)
SUBSEQUENT UTILITIES	The student's model values after the action
UTILITY DIFFERENCES	The differences between the experts and the student's model values
UTILITY RATIOS	The ratios of the student's utilities
SLIDING WINDOW PERFORMANCE	The amount of training occurring over the most recent n decisions
CLOSENESS TO EXPERT	The cosine of the angle between the expert's and student's weight vectors
CONVERGENCE	Yes - Small amount of training of student's model over sliding window No - Larger amount of training of student's model over sliding window
TYPE OF HELP	1 - Expert's considerations requested 2 - Expert's tradeoffs for expert's considerations requested 3 - Expert's tradeoffs for student's considerations requested 4 - Expert's ranking of student's considerations requested
STUDENT WEIGHTS	Student's model weights
STUDENT COST	Student's cost for current problem
EXPERT COST	Expert's would-be cost for current problem

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APPENDIX A

STUDENT HANDOUT

Introduction

You are a subject in an experimental program designed to help develop computer-assisted instruction for teaching electronic troubleshooting. The system enables you to get actual troubleshooting experience in a simulated environment. You will work with a computer terminal which has a keyboard and a CRT display with graphics capability. The goal of the current experimental series is to evaluate the teaching effectiveness of the system under various experimental configurations. Specifically, we're interested in how much and how fast you learn as you work with the system. On-line measures will be used to evaluate your learning progress and to adjust further instruction to your learning needs.

You will be working with the Adaptive Computerized Training System (ACTS). The ACTS is adaptive in that it learns the troubleshooting behavior of the student. For this reason it is important that you be as consistent as possible in your approach to troubleshooting. The more consistent you are, the faster ACTS will be able to learn your particular values and give instructional feedback which is responsive to your learning needs.

Included here-in is an introduction to power supplies, which you should study in order to learn the background material required for your on-line troubleshooting practice. Following the introduction will be a troubleshooting guide, which is to be used for reference during troubleshooting.

INTRODUCTION TO POWER SUPPLIES

A power supply is a source of electrical energy. It supplies the energy needed by various circuits and electrical devices to function. These circuits and electrical devices, being users of electrical energy, are known as loads. The purpose of a power supply is to provide electrical energy or power for use by a load.

A power supply may be either self-contained, such as a battery, or may transform one form of electrical energy into other, more useful forms. In this discussion, we are concerned with the latter.

Electrical energy exists in many different forms and levels. Two primary forms are alternating current, or A.C., and direct current, or D.C. A.C. is characterized by a constantly changing wave of electrical energy; whereas D.C. is characterized by a constant, non-changing level of electrical energy. The magnitude or level of an A.C. or D.C. signal may be of any numerical value, an example being a high level (100), or a low level (10).

Often, the energy requirement of form and magnitude of a load cannot be met by the available source of power. An example of this would be a load requiring a low level D.C. with an available source of power of high level A.C. A power supply may be used to convert the high level A.C. to the low level D.C. required by the load. Such a power supply would have an input to which the source of power would be applied, and an output through which the converted D.C. would be supplied to the load. A power supply may be used to match the requirements of a load with the characteristics of an available power source.

INTRODUCTION TO THE IP-28 POWER SUPPLY

The IP-28 power supply is designed to perform specific operations under specific conditions. Understanding these operations and conditions will help in understanding the IP-28 power supply.

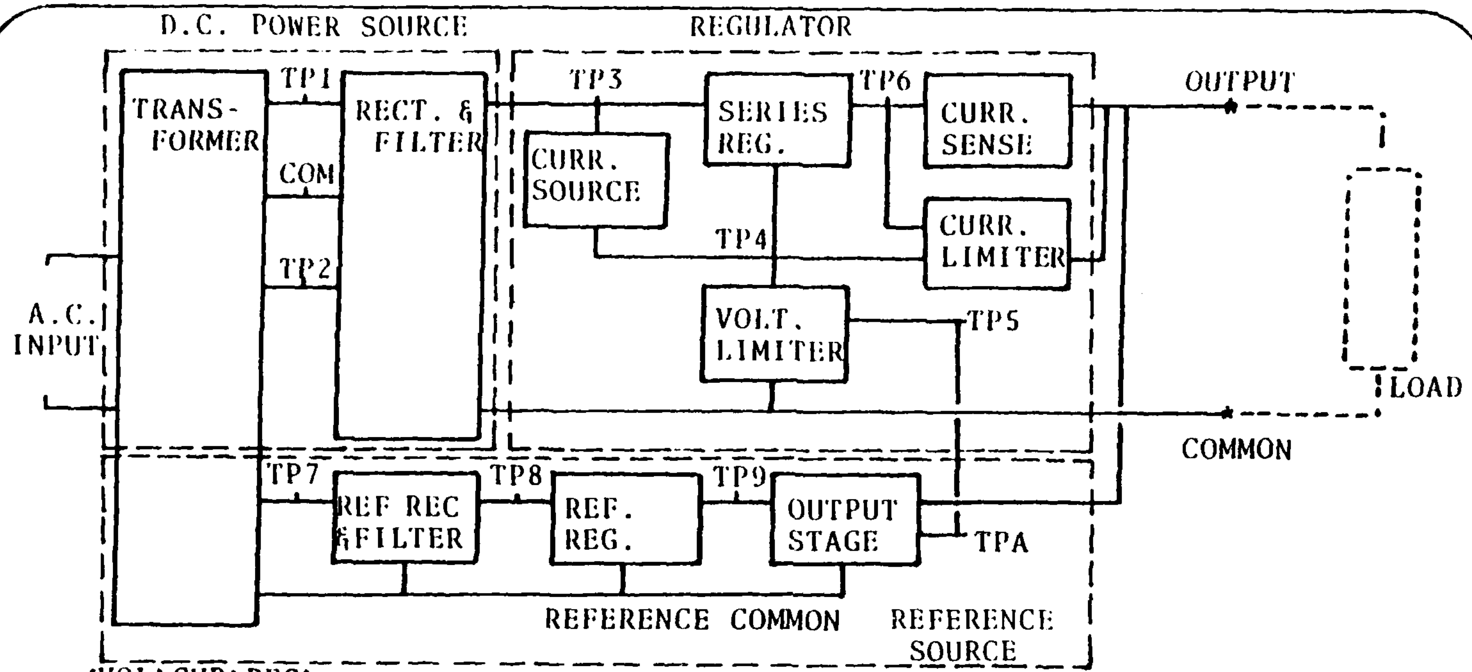
The IP-28 converts a single A.C. input into a single D.C. output. All power used for operation of the IP-28 comes from the single A.C. input. All power used by the load comes from the single D.C. output.

Certain characteristics of the IP-28's D.C. output are maintained, or regulated, at a constant level. This regulation is achieved in the IP-28 by monitoring the output characteristics, and acting to correct any changes. The output characteristic of voltage, or level of electrical energy, and the output characteristic of current, or flow of electrical energy, are both regulated in this way. Because of this, the output of the IP-28 is said to be current and voltage regulated.

The level at which the output voltage and current is regulated is adjustable. Both voltage and current may be adjusted to regulate at high or low. The value of the load dictates whether voltage or current regulation is taking place. Should the load drain excessive current from the output at the regulated voltage value, the current would be regulated. Otherwise, the output voltage would be regulated.

FUNCTIONAL BLOCKS

Within the IP-28, three major functional blocks, the D.C. power source, the reference source, and the regulator (see Figure 1) operate and interact to convert power from the A.C. input into an adjustable D.C. output. Each functional block performs specific operations, which we will now consider.



	VOL	CUR	RES
OUTP			
TP 1			
TP 2			
TP 3			
TP 4			
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

FIGURE 1.
FUNCTIONAL BLOCK DIAGRAM FOR THE IP28 POWER SUPPLY

The D.C. power source converts the A.C. input power to D.C. The D.C. output of the D.C. power source consists of the common line and the connection to the regulator.

The reference source provides an adjustable D.C. output. This adjustable D.C. output is connected to the regulator and an output line. The reference source converts A.C. power carried by the two lines connected to the D.C. power source to the adjustable D.C. output.

The output of the regulator is current or voltage regulated D.C. and is connected to the output of the IP-28. The regulator draws D.C. power from the output of the D.C. power source and passes to the output of the IP-28 the proper D.C. voltage or current level. The voltage level between the line from the reference source to the regulator and common, called the feedback voltage, is used by the regulator to regulate the output voltage.

The feedback voltage level is the result of the difference between the output voltage level and the reference source D.C. output voltage level. Changes in the output voltage or the reference source output voltage will cause the regulator to make an opposite change in the output voltage. The regulated output voltage level can be changed by adjusting the reference source output voltage. The regulated output voltage level can be kept constant if changes in load conditions do not result in an excessive output current level.

D.C. POWER SOURCE MODULES

Each of the functional blocks of the IP-28 can be divided into modules, or small functional units. The subject of this discussion is the modular makeup of the D.C. power source and how these modules operate and interact to perform as the D.C. power source functional block.

The D.C. power source, as a major functional unit of the IP-28 power supply, performs the task of converting the A.C. input power to D.C. The D.C. output of the D.C. power source provides D.C. power to be used by the regulator and to be passed to the output.

The function of the D.C. power source is performed by two modules: the transformer and the rectifier and filter.

The transformer, drawing upon the A.C. input, produces an A.C. output whose voltage and configuration is compatible with the rectifier and filter module. The output of the transformer consists of three lines as displayed in the diagram, Figure 1. The center line is the common line, and the A.C. voltage between the common center line and the two outer lines provides A.C. voltage to the rectifier and filter.

The rectifier and filter convert the A.C. power from the transformer's output to D.C. The output of the rectifier and filter consists of two lines, one connected directly to the regulator and another connected to the regulator and the output common terminal. It is through these connections that the D.C. power output of the rectifier and filter is delivered to the regulator.

REFERENCE SOURCE MODULES

The reference source performs the task of providing an adjustable D.C. voltage needed by the regulator for voltage regulation. Modules contained within the reference source work together to perform this task.

The reference supply is made up of the following modules:

Transformer

Reference Rectifier and Filter (REF RECT & FILTER)

Reference Regulator (REF REG)

Output Stage

Refer to the diagram (Figure 1) and recognize their placement and interconnections.

The reference source shares the transformer with the D.C. power source. The output of the transformer connected to the reference rectifier and filter is A.C. and is separate from the other transformer output. The transformer performs for the reference supply the task of converting the A.C. input voltage to an A.C. voltage needed by the reference rectifier and filter.

The reference rectifier and filter converts the A.C. from the transformer to D.C. The output of the reference rectifier and filter, consisting of the line connected to the reference regulator and the reference common (REF COM) line, supplies D.C. to the reference regulator.

The reference regulator draws upon the D.C. from the reference rectifier and filter and produces a constant D.C. voltage output needed by the output stage.

The line connecting the reference regulator to the reference common line, as it is also with the reference rectifier and filter, is a common input and output line to that module.

The output stage uses the constant D.C. voltage from the reference regulator to produce an adjustable D.C. voltage output. Within the output stage is a means to adjust the D.C. voltage between the line connected from the output stage to the output line, and the line connected to the regulator.

In summary, the transformer converts the A.C. input voltage; the reference rectifier and filter changes the converted A.C. to D.C.; the reference regulator stabilizes the D.C.; and the output stage provides a means for adjusting the D.C. These actions perform the task required of the reference source.

REGULATION MODULES

The regulator passes the proper amount of D.C. voltage or current from the D.C. power source to the output. The regulator has two modes of operation, either voltage regulation or current regulation.

1. VOLTAGE REGULATION MODULES

The modules contained within the regulator which perform voltage regulation are:

Current source (CURR SOURCE)
Series regulator (SERIES REG)
Voltage limiter (VOLT LIMITER)

Refer to the diagram, (Figure 1) and recognize their placement and interconnection.

The current source provides the proper flow of current to the series regulator and to the voltage limiter to insure their operation. The current source draws current from the D.C. power source and outputs a constant and proper amount of current to the series regulator and voltage limiter.

The series regulator is placed between the output and the D.C. power source so that the power to the output can be controlled. The output voltage level of the series regulator is controlled by, and proportional to, the

voltage level between the line connected to the base of the series regulator and common, called the control voltage or control signal.

The voltage limiter conducts different amounts of current from the current source. The more current conducted by the voltage limiter, the lower the control voltage.

The amount of current conducted by the voltage limiter is controlled by the feedback voltage level between the feedback signal connection to the voltage limiter and common. The higher the feedback voltage the higher the current conducted by the voltage limiter and the lower the control voltage.

2. CURRENT REGULATION MODULES

The regulator performs both current and voltage regulation. In addition to the current source, the series regulator, and the voltage limiter, the regulator contains the current sense and current limiter modules.

Current regulation or limiting is the result of the current limiter module causing a drop in the control signal voltage across the current sense.

This voltage drop across the current sense is directly proportional to the output current. When the output current is at a certain level, the voltage drop across the current sense will be high enough to cause the current limiter to reduce the control signal. The output current level at which this occurs, called the current limit level, can be changed by means of an adjustment within the current sense module. When the output current is less than the current limit level, the voltage drop across the current sense will not cause the current limiter to reduce the control voltage.

When the output current is below the current limit level, the current limiter has no effect on output voltage regulation as performed by the current source, the series regulator, and the voltage limiter. If the output current is greater than the current limit level, the current limiter will lower the control signal voltage by conducting current from the current source through the load to common. The resulting drop in the control signal voltage will cause the series regulator to lower the output voltage. The decrease in output voltage will lower the output current until it is at the current limit level.

TROUBLESHOOTING GUIDE

The display will be as shown in Figure 2. Each module is abbreviated with the three letters brightened on your display and underlined in Figure 2. When you must refer to a module (as when you replace a module), it is necessary to use the three letter abbreviations. The tables which follow also use these abbreviations. Notice that various test points are represented on the diagram (e.g., TP1, TP2, etc.). It is necessary to use these three character test point labels to take circuit measurements. The table in the lower left portion of the display (see Figure 2) lists the measurements with three columns corresponding to the three types of measurements: voltage, current and resistance. The outcome of each measurement you take is listed in the appropriate place in the table. Measurement results are presented in a semi-interpreted form to save you the trouble of consulting a table of normal values. Thus all measurements have one of the following outcomes.

Normal (N or blank)
Too High (H)
Too Low (L)
Zero (Ø)

Table 1 lists each fault and its probability of occurrence. A good troubleshooter takes these probabilities into account while making troubleshooting decisions. Table 1 uses the module abbreviations mentioned earlier as well as the following abbreviations to refer to failures.

OPN = Open
SHT = Short
OUT = Output
TRAN = Transistor
RES = Resistor

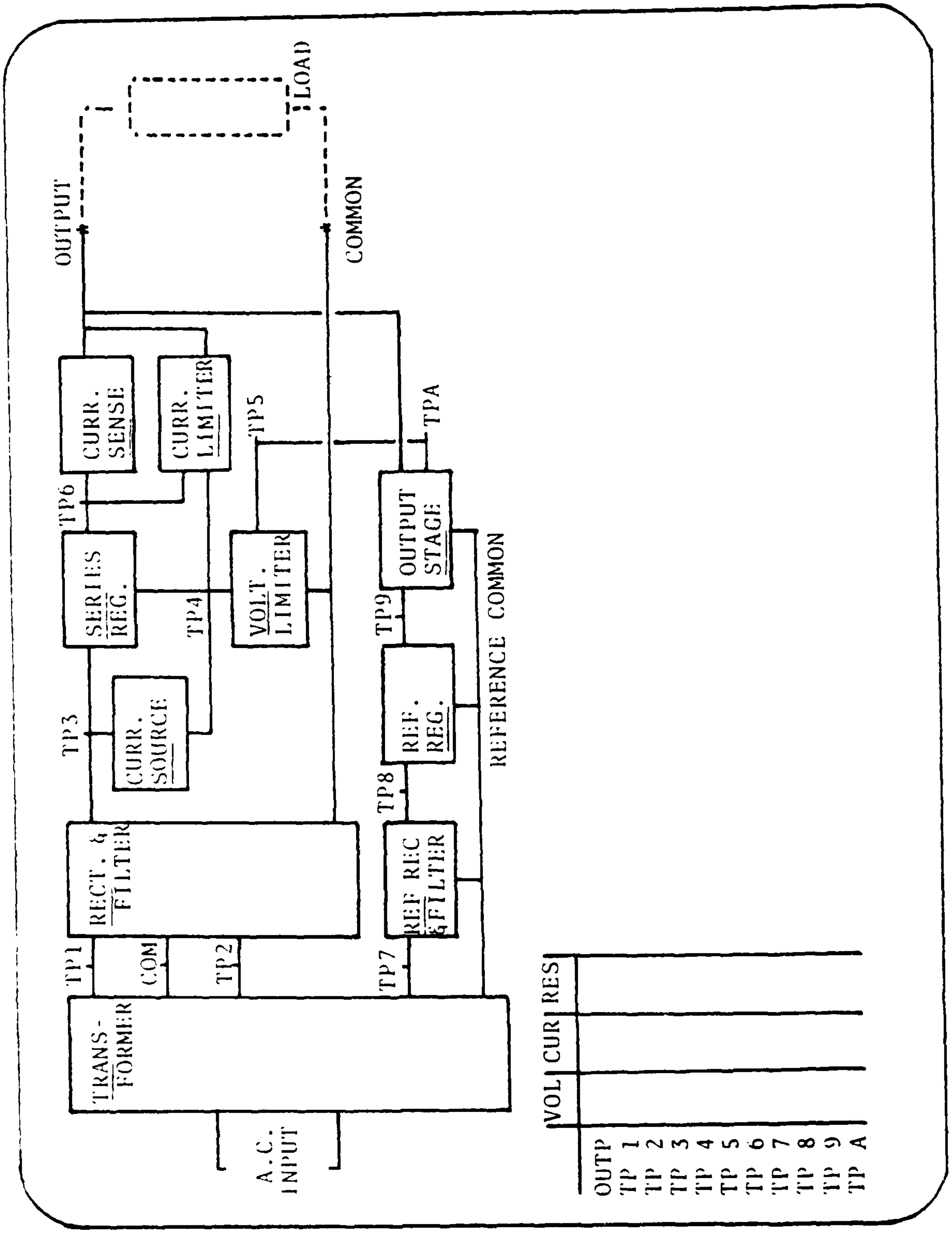


FIGURE 2.
DISPLAY DIAGRAM

TABLE 1

MODULE FAULT PROBABILITIES

MODULE FAULTS		PROBABILITY OF OCCURRENCE
MODULE	FAILURE	
LIM	OPN TRAN	.11
LIM	SHUT TRAN	.09
REC	OPN OUT	.05
REG	OPN RES	.06
REF	OPN DIODE	.06
SEN	SHT RES	.09
SER	OPN RES	.11
SOU	Ø OUT	.10
STA	OPN RES	.04
STA	SHT RES	.05
TRA	OPN OUT	.03
TRA	Ø REFOU	.02
VOL	OPN TRAN	.10
VOL	SHT	.09

Table 2 gives the correspondence between faults and measurement outcomes. The abbreviations used in this table were explained earlier. The information presented in Table 2 represents a substantial amount of the information used by the ACTS' expert model to troubleshoot the circuit. You should find it useful when considering measurements.

Table 3 gives the list of recognized responses and their corresponding measurement cost or replacement cost. (When a module is replaced it is brightened on the display as you will see the first time you replace a module.)

TABLE 2

MODULE FAULTS		CIRCUIT OPERATING CONDITION																															
		VOLTAGE REGULATION											CURRENT REGULATION											POWER OFF									
MODULE	FAILURE	OUT	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TPA	OUT	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TPA	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TPA
		DC	AC	AC	DC	DC	DC	DC	AC	DC	DC	DC	DC	AC	AC	DC	DC	DC	DC	AC	DC	DC	DC	RE	RE	RE	RE	RE	RE	RE	RE	RE	RE
LIM	OPN TRAN												H				H	H	H														
LIM	SHT TRAN	L				L	L	L					L				L	L	L								L						
REC	OPN OUT	L			L	L	L	L					L			L	L	L	L														
REG	OPN RES	L				L		L			L	L	L				L	H	L			L	L										
REI	OPN DIODE	L				L		L		L	L	L	L				L	H	L		L	L	L										
SEN	SHT RES												H				H	H	H														
SER	OPN TRAN	L				H	L	L					L				H	L	L														
SOU	Ø OUT	L				L	L	L					L				L	L	L														
STA	OPN RES	H				H	L	H				L						H					L										H
STA	SHT RES	H				H		H				L						L					L										L
TRA	OPN OUT	L	L	L	L	L	L	L					L	L	L	L	L	L	L					H	H								
TRA	Ø REF OUT	L				L		L	L	L	L	L	L				L	H	L	L	L	L	L							H			
VOL	OPN TRAN	H				H	H	H				L																					
VOL	SHT	L				L	L	L					L				L	L	L								Ø						

BLANK SPACE IS NORMAL; L = LOW; H = HIGH; Ø = ZERO.
MEASUREMENTS TP1 TO TP6 MADE IN REFERENCE TO COMMON. MEASUREMENTS TP7 TO TPA MADE IN REFERENCE TO REFERENCE COMMON.

TABLE 3

LIST OF RECOGNIZED RESPONSES AND THEIR COST:

TP1ACVR	$4	TP1ACCR	$4	TP1REPO	$10	TRA	$98
TP2ACVR	$4	TP2ACCR	$4	TP2REPO	$10	REC	$70
TP3ACVR	$4	TP3DCCR	$4	TP3REPO	$10	SOU	$90
TP4DCVR	$8	TP4DCCR	$8	TP4REPO	$10	VOL	$80
TP5DCVR	$8	TP5DCCR	$8	TP5REPO	$10	LIM	$80
TP6DCVR	$4	TP6DCCR	$4	TP6REPO	$10	STA	$50
TP7ACVR	$4	TP7ACCR	$4	TP7REPO	$10	SER	$90
TP8DCVR	$4	TP8DCCR	$4	TP8REPO	$10	SEN	$50
TP9DCVR	$4	TP9DCCR	$4	TP9REPO	$10	REG	$70
TPADCVR	$8	TPADCCR	$8	TPAREPO	$10	REF	$70

ATTRIBUTES

There are three attributes which should be used as criteria for selecting an action:

1. Decrease in uncertainty. This is the decimal fraction (i.e., a number between 0 and 1) representing the proportion of faults expected to be eliminated by the considered action.

2. Expected faulty module isolation. This is the decimal fraction (i.e., a number between 0 and 1) representing the proportion of faulty modules expected to be eliminated by the current action.

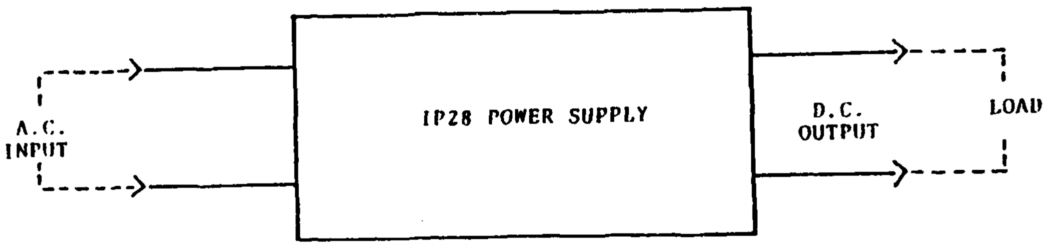
3. Cost. This is the cost of the action.

APPENDIX B

SAMPLE INSTRUCTIONAL SEQUENCES

2.7 PRELIMINARY LECTURE

A lecture covering the overall functional requirements of the IP28 Power Supply is displayed. Also displayed is a diagram relating input and output connections.



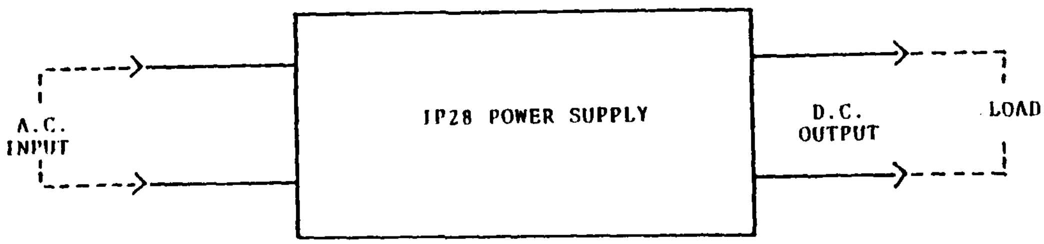
INTRODUCTION TO THE IP28 POWER SUPPLY

THE IP28 POWER SUPPLY IS DESIGNED TO PERFORM SPECIFIC OPERATIONS UNDER SPECIFIC CONDITIONS. AN UNDERSTANDING OF THESE OPERATIONS AND CONDITIONS WILL HELP YOU TO UNDERSTAND THE IP28 POWER SUPPLY. THE IP28 CONVERTS A SINGLE A.C INPUT INTO A SINGLE D.C. OUTPUT. ALL POWER USED TO OPERATE THE IP28 COMES FROM THE SINGLE A.C INPUT. AFTER THE IP28 POWER SUPPLY CONVERTS THE A.C INPUT INTO D.C., THE D.C. OUTPUT PROVIDES ALL THE POWER REQUIRED BY THE LOAD.

THE IP28 POWER SUPPLY CONVERTS A SINGLE A.C. INPUT INTO A SINGLE D.C. OUTPUT REQUIRED BY THE LOAD.

PRESS RETURN TO CONTINUE

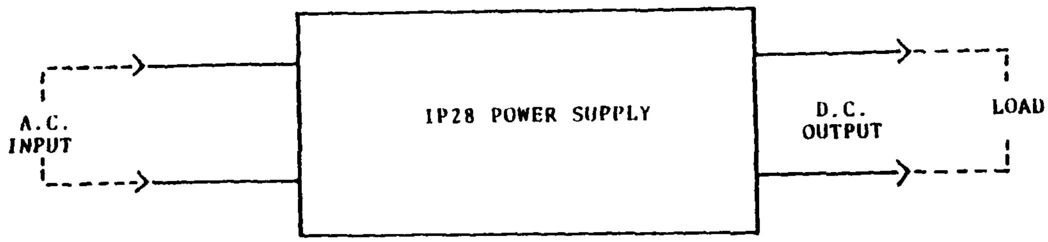
Following understanding of the material, the student responds by pressing the return key, and the lecture units continue.



THE OUTPUT OF THE IP28 IS REGULATED. CERTAIN CHARACTERISTICS OF THE D.C. OUTPUT ARE MAINTAINED, OR REGULATED, TO MAINTAIN A CONSTANT LEVEL. THIS REGULATION IS ACHIEVED BY MONITORING THE OUTPUT CHARACTERISTICS, AND ACTING TO CORRECT CHANGES. OUTPUT CHARACTERISTICS OF VOLTAGE (LEVEL OF ELECTRICAL ENERGY) AND THE CURRENT (FLOW OF ELECTRICAL ENERGY) ARE BOTH REGULATED. THUS, THE OUTPUT OF THE IP28 IS SAID TO BE CURRENT AND VOLTAGE REGULATED.

THE OUTPUT OF THE IP28 IS REGULATED TO MAINTAIN CONSTANT VOLTAGE AND CURRENT LEVELS.

PRESS RETURN TO CONTINUE

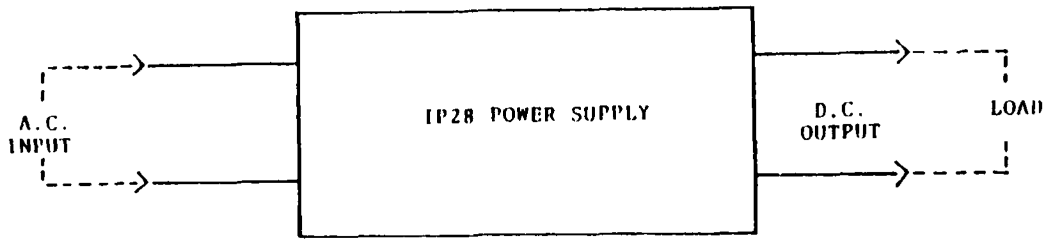


THE LEVELS AT WHICH OUTPUT VOLTAGE AND CURRENT ARE REGULATED CAN BE ADJUSTED. HIGH OR LOW LEVELS MAY BE SELECTED TO REGULATE BOTH THE VOLTAGE AND THE CURRENT. THE VALUE REQUIRED BY THE LOAD DETERMINES WHETHER VOLTAGE OR CURRENT REGULATION WILL OCCUR. SHOULD THE LOAD DRAW EXCESSIVE CURRENT FROM THE OUTPUT, AT THE REGULATED VOLTAGE VALUE, THE CURRENT WOULD BE REGULATED. OTHERWISE, THE OUTPUT VOLTAGE WOULD BE REGULATED.

REGULATION OF OUTPUT VOLTAGE OR CURRENT ARE ADJUSTABLE AND DETERMINED BY LOAD REQUIREMENTS.

PRESS RETURN TO CONTINUE

At the end of several units, which comprise the entire instructional objective, the student's understanding of the concepts discussed in the lecture is evaluated. The student may select one of the several options displayed. In this example, the student requests additional information on concept #2.



YOU SHOULD NOW UNDERSTAND THE FOLLOWING CONCEPTS;

(1) IP28 INPUTS AND OUTPUTS,
(2) CHARACTERISTICS OF VOLTAGE AND CURRENT,
(3) VOLTAGE AND CURRENT CIRCUIT CONNECTIONS,
(4) IP28 REGULATION,
(5) CURRENT OR VOLTAGE REGULATION.

AT THIS POINT SEVERAL OPTIONS ARE AVAILABLE TO YOU,

1. IF YOU FEEL YOU UNDERSTAND EACH OF THE CONCEPTS ABOVE, TYPE "RETURN" AND YOU WILL BE GIVEN A SHORT TEST ON THIS MATERIAL.

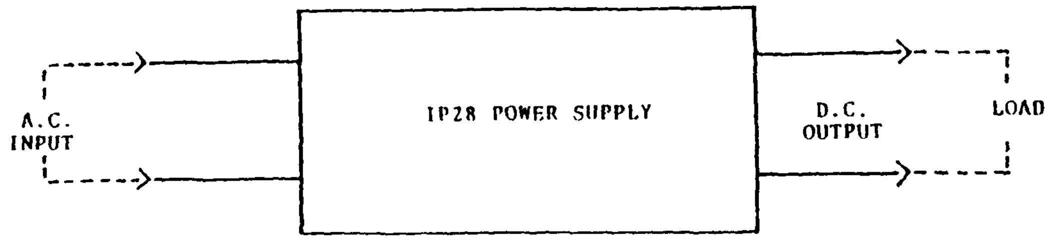
2. IF YOU ARE NOT SURE ABOUT A CONCEPT PRESENTED IN THE LECTURE, TYPE THE LETTER "H" FOLLOWED BY THE NUMBER OF THE CONCEPT (E.G., CHARACTERISTICS OF VOLTAGE AND CURRENT) AND "RETURN" THIS ENTRY WILL PROVIDE YOU MORE INFORMATION ABOUT THE CONCEPT YOU SELECT.

3. IF YOU WOULD LIKE TO REREAD THIS LECTURE, TYPE "H" AND "RETURN."

FOLLOWING YOUR REVIEW OF THE LECTURE AND/OR ADDITIONAL MATERIAL, TYPE "RETURN" TO RECEIVE THE TEST ON THE MATERIAL.

The student responds to the options by typing "H2", followed by "RETURN."

Additional lecture material covering concept number 2 is displayed. First, a statement succinctly stating the concept is displayed, followed by a detailed example.

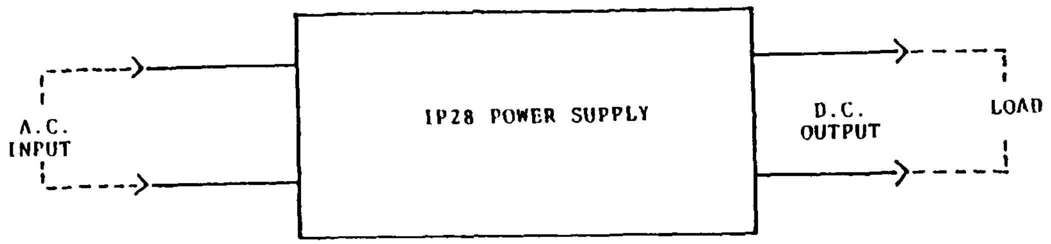


2. ELECTRICAL ENERGY CAN BE EXPRESSED IN TERMS OF VOLTAGE AND CURRENT. VOLTAGE DESCRIBES THE MAGNITUDE OF ELECTRICAL ENERGY AND THE CURRENT, THE FLOW OF ELECTRICAL ENERGY.

THE DIFFERENCE BETWEEN VOLTAGE AND CURRENT IS ANALOGOUS TO THE WATER BEHIND A HYDRO-ELECTRICAL DAM AND THE FLOW OF RELEASED WATER THROUGH THE TURBINES. IN THIS EXAMPLE, THE WATER BEHIND THE DAM IS LIKENED TO VOLTAGE, THE GREATER THE WATER LEVEL GEHIND THE DAM THE GREATER ITS POTENTIAL FOR GENERATING ELECTRICAL POWER. THE AMOUNT OF WATER FLOWING THROUGH THE TURBINES IS LIKENED TO CURRENT. THUS THE COMBINATION OF THE HEIGHT OF THE WATER (VOLTAGE) AND THE AMOUNT FLOWING THROUGH THE TURBINES (CURRENT) PRODUCES ELECTRICAL POWER.

PRESS CARRIAGE RETURN TO CONTINUE.

The student is again asked to evaluate his understanding of the concepts. The options are again the same. This time, the student requests to receive the test material by typing "RETURN."



YOU SHOULD NOW UNDERSTAND THE FOLLOWING CONCEPTS;
(1) IP28 INPUTS AND OUTPUTS.
(2) CHARACTERISTICS OF VOLTAGE AND CURRENT.
(3) VOLTAGE AND CURRENT CIRCUIT CONNECTIONS.
(4) IP28 REGULATION.
(5) CURRENT OR VOLTAGE REGULATION.

AT THIS POINT SEVERAL OPTIONS ARE AVAILABLE TO YOU.

1. IF YOU FEEL YOU UNDERSTAND EACH OF THE CONCEPTS ABOVE, TYPE "RETURN" AND YOU WILL BE GIVEN A SHORT TEST ON THIS MATERIAL.

2. IF YOU ARE NOT SURE ABOUT A CONCEPT PRESENTED IN THE LECTURE, TYPE THE LETTER "H" FOLLOWED BY THE NUMBER OF THE CONCEPT (E.G., CHARACTERISTICS OF VOLTAGE AND CURRENT) AND "RETURN" THIS ENTRY WILL PROVIDE YOU MORE INFORMATION ABOUT THE CONCEPT YOU SELECT.

3. IF YOU WOULD LIKE TO REREAD THIS LECTURE, TYPE "H" AND "RETURN."

FOLLOWING YOUR REVIEW OF THE LECTURE AND/OR ADDITIONAL MATERIAL, TYPE "RETURN" TO RECEIVE THE TEST ON THE MATERIAL.

The first question is presented to the student.

```
WHICH OF THE FOLLOWING IS FALSE:

   A.  THE IP28 HAS A SINGLE A.C. INPUT AND A SINGLE
       D.C. OUTPUT.

   B.  THE INPUT OF THE POWER SUPPLY IS WHERE THE
       EXTERNAL POWER SOURCE IS APPLIED.

   C.  THE TOTAL NUMBER OF LINES OR CONNECTIONS GOING
       INTO AND OUT OF THE IP28 IS FOUR.

   D.  THE LOAD DRAWS A.C. POWER FROM THE OUTPUT.

   E.  NONE OF THE ABOVE.

PLEASE TYPE THE APPROPRIATE LETTER KEY, FOLLOWED BY A CARRIAGE
RETURN, TO GIVE YOUR ANSWER.
```

The student responds by typing the answer on the keyboard, in this case, by pressing "D" followed by "RETURN."

The answer the student selected was correct. The tested concepts are restated.

```
WHICH OF THE FOLLOWING IS FALSE:

   A.  THE IP28 HAS A SINGLE A.C. INPUT AND A SINGLE
       D.C. OUTPUT.

   B.  THE INPUT OF THE POWER SUPPLY IS WHERE THE
       EXTERNAL POWER SOURCE IS APPLIED.

   C.  THE TOTAL NUMBER OF LINES OR CONNECTIONS GOING
       INTO AND OUT OF THE IP28 IS FOUR.

   D.  THE LOAD DRAWS A.C. POWER FROM THE OUTPUT.

   E.  NONE OF THE ABOVE.

PLEASE TYPE THE APPROPRIATE LETTER KEY, FOLLOWED BY A CARRIAGE
RETURN, TO GIVE YOUR ANSWER.
D.
CORRECT. THE LOAD DRAWS D.C. POWER FROM THE OUTPUT, NOT A.C.

THEREFORE, THE FOLLOWING ARE TRUE STATEMENTS:

   A.  THE IP28 HAS A SINGLE A.C. INPUT AND SINGLE
       D.C. OUTPUT.

   B.  THE INPUT OF THE POWER SUPPLY IS WHERE THE
       EXTERNAL POWER SOURCE IS APPLIED.

   C.  THE TOTAL NUMBER OF LINES GOING INTO AND OUT FROM
       THE IP28 IS FOUR.

   D.  THE LOAD DRAWS D.C. POWER FROM THE IP28 OUTPUT.

PRESS CARRIAGE RETURN TO CONTINUE.
```

Following recognition of the correct answer, the student responds by pressing "RETURN," and the second question is presented to the student.

THE OUTPUT OF THE IP28 IS NOT;

A. VOLTAGE REGULATED.

B. CURRENT REGULATED.

C. CONNECTED TO THE LOAD.

D. FIXED OR NON-ADJUSTABLE.

E. MADE UP OF TWO LINES.

PLEASE TYPE THE APPROPRIATE LETTER KEY, FOLLOWED BY A CARRIAGE RETURN, TO GIVE YOUR ANSWER.

The student responds by typing the answer on the keyboard. Assuming the student responds by pressing "C" followed by "RETURN," the following display will be presented.

```
THE OUTPUT OF THE IP28 IS NOT:

  A.  VOLTAGE REGULATED.

  B.  CURRENT REGULATED.

  C.  CONNECTED TO THE LOAD.

  D.  FIXED OR NON-ADJUSTABLE.

  E.  MADE UP OF TWO LINES.

PLEASE TYPE THE APPROPRIATE LETTER KEY, FOLLOWED BY A CARRIAGE
RETURN, TO GIVE YOUR ANSWER.
C.
WRONG.  THE IP28 SUPPLIES D.C. POWER THROUGH THE D.C. OUTPUT TO
THE LOAD.  THE LOAD DRAWS POWER FROM THE IP28'S D.C. OUTPUT.
THEREFORE, IN ORDER FOR THE IP28 AND THE LOAD TO WORK AS
INTENDED, THE OUTPUT OF THE IP28 IS CONNECTED TO THE LOAD.

PRESS CARRIAGE RETURN TO CONTINUE.
```

The answer selected by the student was incorrect. An explanation is provided explaining why the answer was incorrect. After the student responds by pressing "RETURN," the third question is presented to the student.

WHICH OF THE FOLLOWING MUST ALWAYS CHANGE THE OUTPUT VOLTAGE OF THE IP28:

A. LOWERING THE VALUE OF THE LOAD, CAUSING LESS POWER TO BE USED.

B. INCREASING THE VALUE OF THE LOAD, CAUSING MORE POWER TO BE USED.

C. INCREASING THE CURRENT REGULATION VALUE.

D. LOWERING THE CURRENT REGULATION VALUE TO ZERO AND HENCE CAUSING CURRENT REGULATION.

E. INCREASING THE VOLTAGE REGULATION VALUE DURING CURRENT REGULATION.

PLEASE TYPE THE APPROPRIATE LETTER KEY, FOLLOWED BY A CARRIAGE RETURN, TO GIVE YOUR ANSWER.

The student responds by pressing "D" followed by "RETURN." Since the answer the student selected was correct, the correct concept is restated.

```
WHICH OF THE FOLLOWING MUST ALWAYS CHANGE THE OUTPUT VOLTAGE
OF THE IP28:

   A.  LOWERING THE VALUE OF THE LOAD, CAUSING LESS
       POWER TO BE USED.

   B.  INCREASING THE VALUE OF THE LOAD, CAUSING MORE
       POWER TO BE USED.

   C.  INCREASING THE CURRENT REGULATION VALUE.

   D.  LOWERING THE CURRENT REGULATION VALUE TO ZERO
       AND HENCE CAUSING CURRENT REGULATION.

   E.  INCREASING THE VOLTAGE REGULATION VALUE DURING
       CURRENT REGULATION.

PLEASE TYPE THE APPROPRIATE LETTER KEY, FOLLOWED BY A CARRIAGE
RETURN, TO GIVE YOUR ANSWER.
D.
CORRECT.  ANY ACTION CAUSING THE OUTPUT OF THE IP28 TO CHANGE
FROM A VOLTAGE REGULATION MODE TO A CURRENT REGULATION MODE
WILL CAUSE THE OUTPUT VOLTAGE TO CHANGE.  SUCH ACTIONS MAY BE
INCREASING THE POWER CONSUMPTION OF THE LOAD AND LOWERING THE
CURRENT REGULATION VALUE.

PRESS CARRIAGE RETURN TO CONTINUE.
```

This lecture represents the format used for preliminary units. Other preliminary objectives may be added as the need arises. During these lectures, the students are taught and tested in an iterative fashion until they are familiar with the material and can be advanced to the troubleshooting objective.

2.8 Troubleshooting Lecture and Presentation

For the troubleshooting objective, the introductory material is presented in a similar format, namely in short, easily understood paragraphs, which include an explanation of the troubleshooting task.

TROUBLESHOOTING INTRODUCTION

YOU WILL NOW HAVE AN OPPORTUNITY TO TRY YOUR HAND AT TROUBLESHOOTING THE IP-28 POWER SUPPLY. THE CIRCUIT WILL BE DISPLAYED FOR YOU ON THE SCREEN. A SINGLE FAULT WILL BE PRESENT SOMEWHERE IN THE CIRCUIT, AND THE SYMPTOMS OF THE FAULT WILL BE DISPLAYED BELOW THE CIRCUIT. YOUR JOB WILL BE TO MAKE ADDITIONAL TESTS UNTIL YOU CAN LOCATE THE FAULTY MODULE AND REPLACE IT.

PRESS "RETURN" TO CONTINUE.

The explanation of the task continues over several frames.

TWO TYPES OF ACTIONS ARE POSSIBLE FOR DIAGNOSING THE FAULT; 1) MEASUREMENTS AND 2) MODULE REPLACEMENTS. EACH OF THESE ACTIONS WILL RESULT IN DIFFERENT COSTS AND DIFFERENT INFORMATION CONCERNING THE FAULTS. THE OBJECTIVE WILL BE TO EXPEND THE LEAST COSTS TO DIAGNOSE AND FIX THE FAULT.

PRESS "RETURN" TO CONTINUE.

TO GO BACK TO THE PREVIOUS PAGE, PRESS "B" AND THEN "RETURN".

SELECTION OF AN ACTION WILL INVOLVE TWO STAGES: (1) DETERMINATION OF FOUR USEFUL ACTIONS THAT COULD BE MADE, AND (2) SELECTION OF ONE OF THE FOUR ACTIONS. AFTER TAKING THE ACTION, THE OUTCOME WILL BE SHOWN ON THE CIRCUIT. YOU WILL CONTINUE TO LIST POSSIBLE ACTIONS AND MAKE CHOICES UNTIL THE FAULT IS DIAGNOSED AND THE BAD MODULE REPLACED.

PRESS "RETURN" TO CONTINUE.

TO GO BACK TO THE PREVIOUS PAGE, PRESS "B" AND THEN "RETURN".

IT WAS MENTIONED IN YOUR EARLIER SESSION THAT YOU SHOULD CHOOSE ACTIONS ON THE BASIS OF THREE FACTORS - UNCERTAINTY REDUCTION, FAULT ISOLATION, AND COST. THE FIRST OF THESE, UNCERTAINTY REDUCTION, IS THE NUMBER OF POSSIBLE FAULTS THAT ARE EXPECTED TO BE ELIMINATED BY THIS MEASUREMENT. THE SECOND FACTOR, FAULT ISOLATION, IS HOW MUCH THE ACTION "CLUSTERS" THE REMAINING FAULTS INTO FEWER MODULES. THE FINAL FACTOR, COST, REPRESENTS THE TIME AND MATERIALS REQUIRED BY THE ACTION. A MODULE REPLACEMENT HAS A HIGH COST; A VOLTAGE, CURRENT, OR RESISTANCE MEASUREMENT HAS A LOW COST.

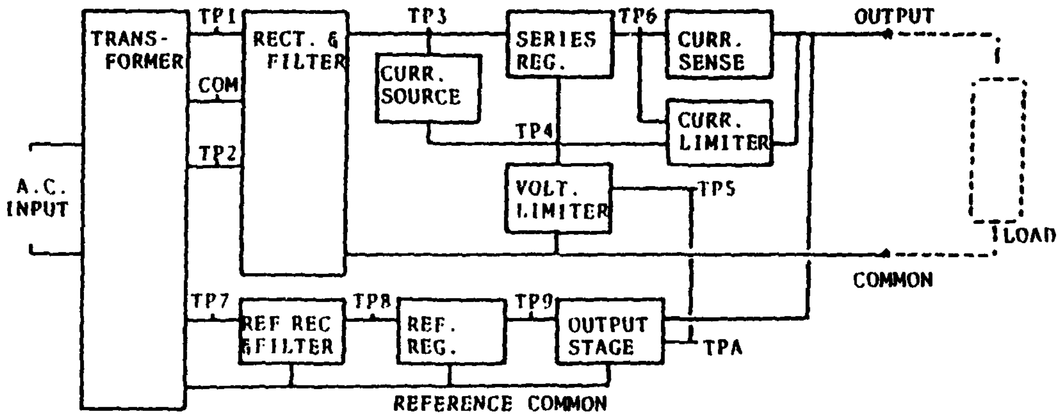
PRESS "RETURN" TO CONTINUE.

TO GO BACK TO THE PREVIOUS PAGE, PRESS "B" AND THEN "RETURN".

TO AID YOU IN THE LEARNING PROCESS, SEVERAL FORMS OF FEEDBACK ARE AVAILABLE TO YOU. IF YOU ARE UNSURE AS TO WHAT ACTIONS TO CONSIDER, YOU CAN HAVE THE SYSTEM DISPLAY A SET OF POSSIBLE ACTIONS AND THE REASONS WHY THEY ARE GOOD. IF YOU ARE UNCERTAIN AS TO WHAT OUTCOMES MAY OCCUR, YOU CAN REQUEST A DISPLAY OF THE POSSIBLE OUTCOMES. YOUR STRATEGY OF SELECTING MEASUREMENTS WILL BE ANALYZED AND CORRECTIVE FEEDBACK GIVEN.

PRESS "RETURN" TO BEGIN TROUBLESHOOTING.

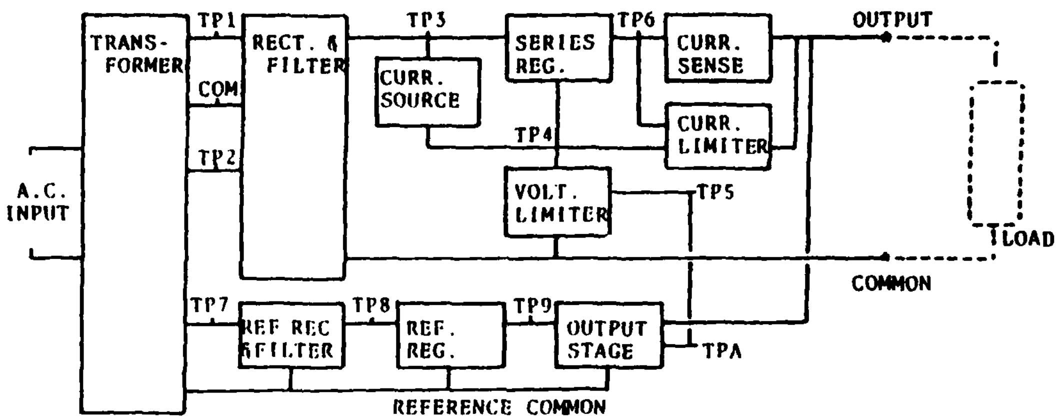
Following the introduction to the troubleshooting task, the system generates a modular diagram of a circuit and a fault table. Shown here, is the diagram of the IP28 power supply, which consists of 10 modules, divided into three major functional blocks and 10 test points. Circuit measurements taken at these points can be of three types: voltage, current, or resistance. Explanations of the modules, their functions, and the types of measurements that can be made are given to the students in the form of a handout and troubleshooting guide. During the course of the troubleshooting objective, this guide may be referred to or not at the student's discretion.



TYPE "RETURN" TO CONTINUE.

	VOL	CUR	RES
OUTP			
TP 1			
TP 2			
TP 3			
TP 4			
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

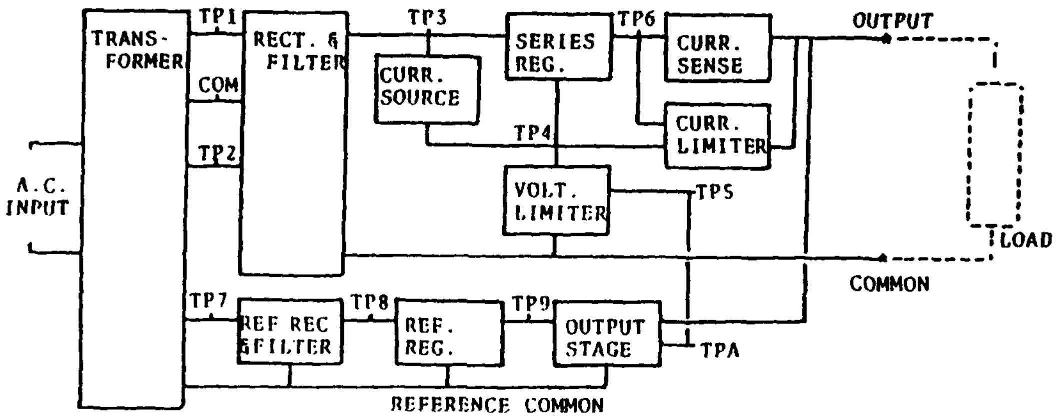
Each troubleshooting problem consists of a simple fault, which the student must locate and correct by replacing the faulty module. The initial output symptoms are displayed in the table.



	VOL	CUR	RES
OUTP	L	L	
TP 1			
TP 2			
TP 3			
TP 4			
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

TYPE "RETURN" TO CONTINUE.

To begin troubleshooting, the student is asked to select appropriate actions. The student may select help, if desired, but has not chosen to do so in the present example.



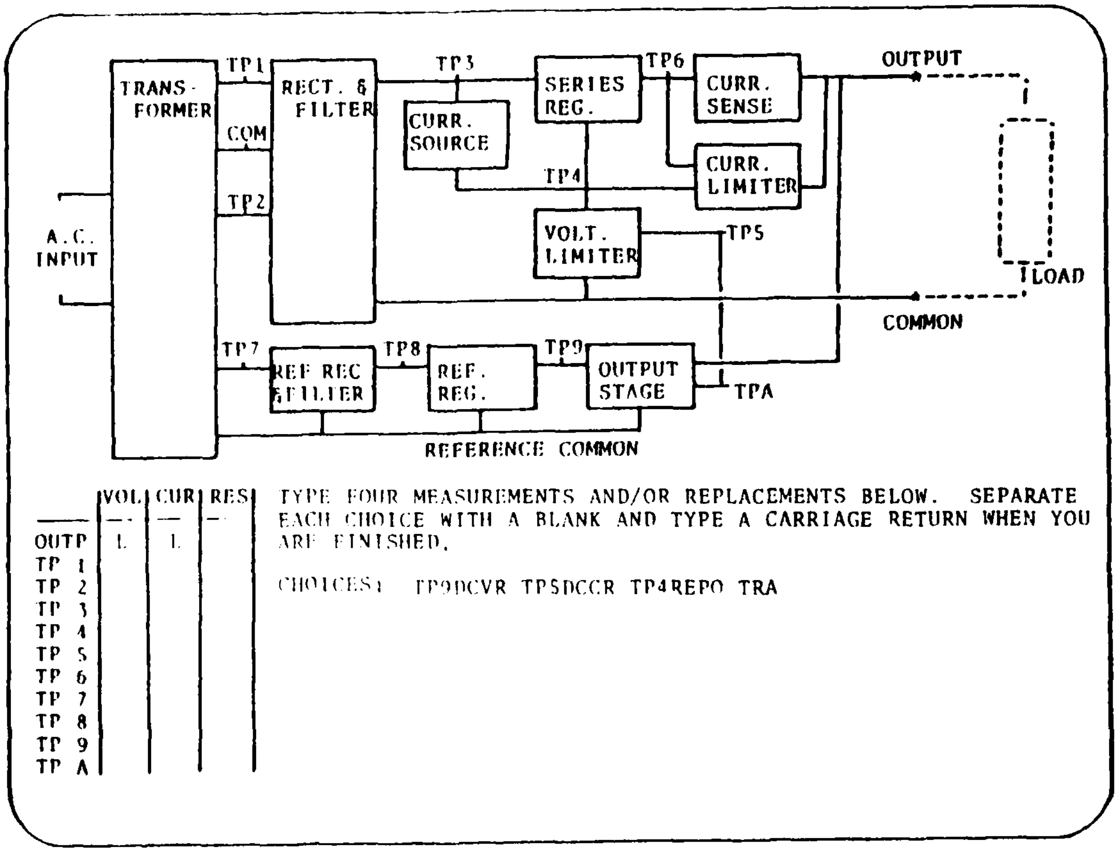
	VOL	CUR	RES
OUTP	L	L	
TP 1			
TP 2			
TP 3			
TP 4			
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

YOU MUST SELECT FOUR ACTIONS WHICH WOULD BE USEFUL IN INDETIFYING AND/OR REPAIRING THE FAULT.

IF YOU ARE READY TO ENTER YOUR FOUR POSSIBLE ACTIONS, THEN PRESS "RETURN".

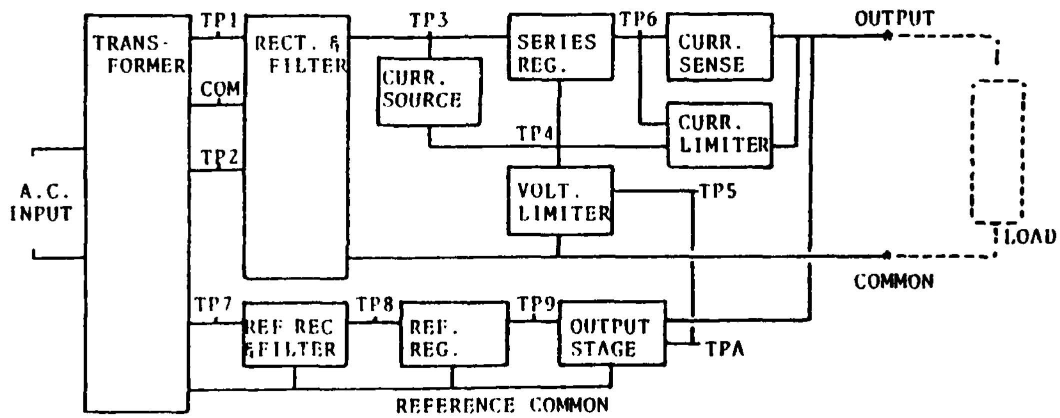
FOR HELP ABOUT POSSIBLE ACTIONS TO TAKE "H", THEN PRESS "RETURN".

When asked to select four measurements or replacements, students may refer to the list of available actions in the troubleshooting guide, or they may type in selections without reference to the guide. If choices are made which are not legitimate actions (e.g., TP5ACVR, instead of TP5DCVR), the choices are rejected by the system, and new choices need to be typed in. In the following example, the student types in acceptable measurements and replacements.



The student's four considerations are listed, along with their attribute levels, and the student is asked to select one of the actions, using the listed attribute levels as a guide. The result of the selected measurement is indicated in the table. In the following example, the student selected "TP4REPO," and the outcome of this measurement was normal.

If the attribute levels for all four considerations appear unsatifactory to the student, the option is available for rejecting all four considerations and selecting new ones. In this case, the student would type "N" and then press "RETURN" and four new actions could be selected.



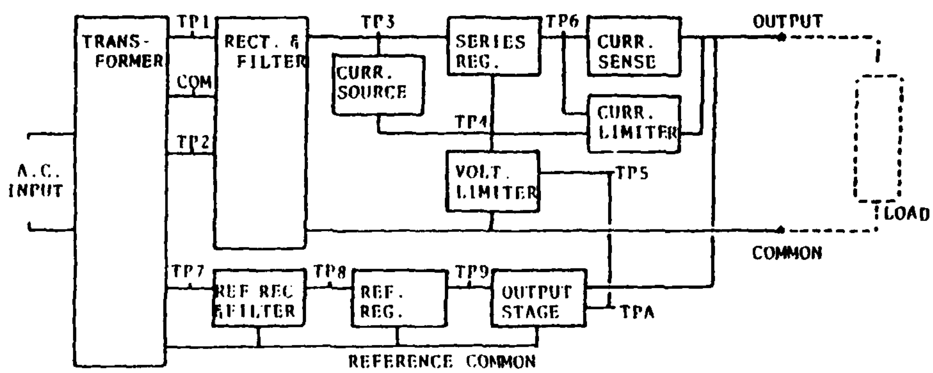
	VOL	CUR	RES
OUTP	L	L	
TP 1			
TP 2			
TP 3			
TP 4			N
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

LISTED BELOW ARE THE FOUR CONSIDERED ACTIONS AND THEIR ATTRIBUTE LEVELS.

ACTION	DECREASE IN UNCERTAINTY	FAULT ISOLATION	COST
1. TP9DCVR	+.40	+.33	+4.00
2. TP5DCCR	+.40	+.33	+8.00
3. TP4REPO	+.41	+.43	+10.00
4. TRA	+.28	+.19	+98.00

TO SELECT AN ACTION, TYPE ITS NAME, THEN PRESS "RETURN."
TP4REPO

Measurements continue to be taken in this fashion until the fault has been isolated. If the student is unsure what to do, "Help" is available at several points of the troubleshooting phase. In the following example, the student is again asked to select four actions, but this time, the student responds by requesting help.



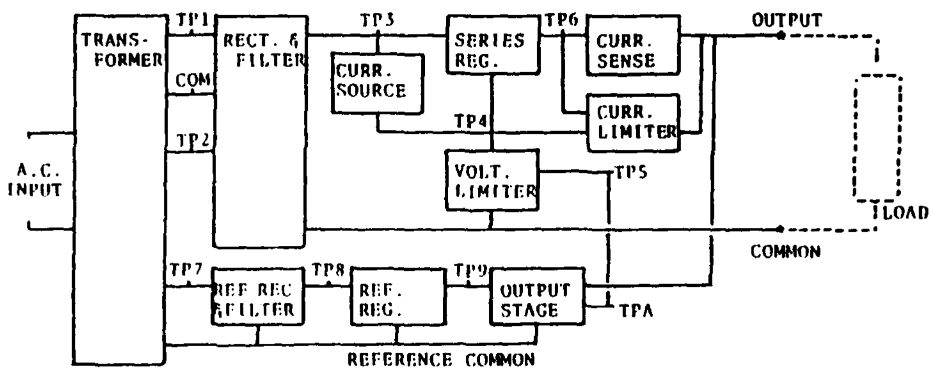
	VOL	CUR	RES
OUTP	L	L	
TP 1			
TP 2			
TP 3			
TP 4			N
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

YOU MUST SELECT FOUR ACTIONS WHICH WOULD BE USEFUL IN INDETIFYING AND/OR REPAIRING THE FAULT.

IF YOU ARE READY TO ENTER YOUR FOUR POSSIBLE ACTIONS, THEN PRESS "RETURN".

FOR HELP ABOUT POSSIBLE ACTIONS TO TAKE "H", THEN PRESS "RETURN".

The instructor's considerations are displayed in an effort to help the student make selections.



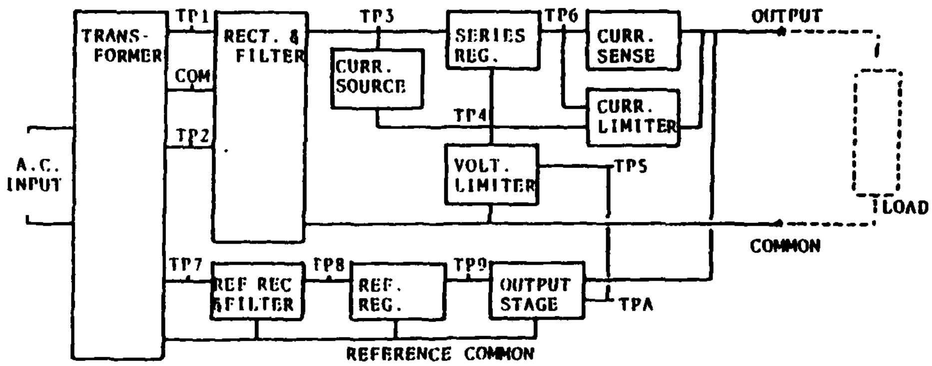
	VOL	CUR	RES
OUTP	L	L	
TP 1			
TP 2			
TP 3			
TP 4			N
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

UNDER THESE CIRCUMSTANCES, THE INSTRUCTOR WOULD CONSIDER THE FOLLOWING FOUR ACTIONS:

TP9DCVR
TPADCVR
TP5DCCR
TP9DCCR

TO CONTINUE PRESS "RETURN".

The reasons for the instructor's choices are displayed.

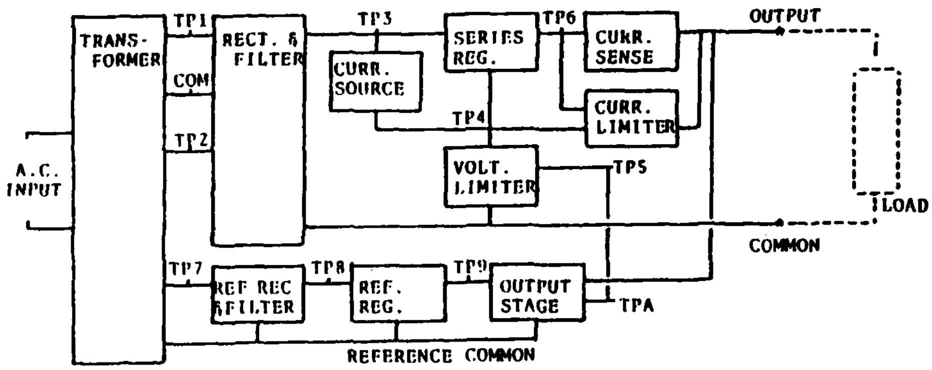


	VOL	CUR	RES
OUTP	L	L	
TP 1			
TP 2			
TP 3			
TP 4			N
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

THE INSTRUCTOR CONSIDERS THESE ACTIONS BECAUSE OF THE FOLLOWING REASONS:

	ACTION	OUTCOME	PROB.	FAULTS ELIM.	COST
1)	TP9DCVR	L	+.32	4/7	4
		N	+.67	3/7	
2)	TPADCVR	L	+.32	4/7	8
		N	+.67	3/7	

PRESS "RETURN" FOR FINAL TWO ACTIONS.



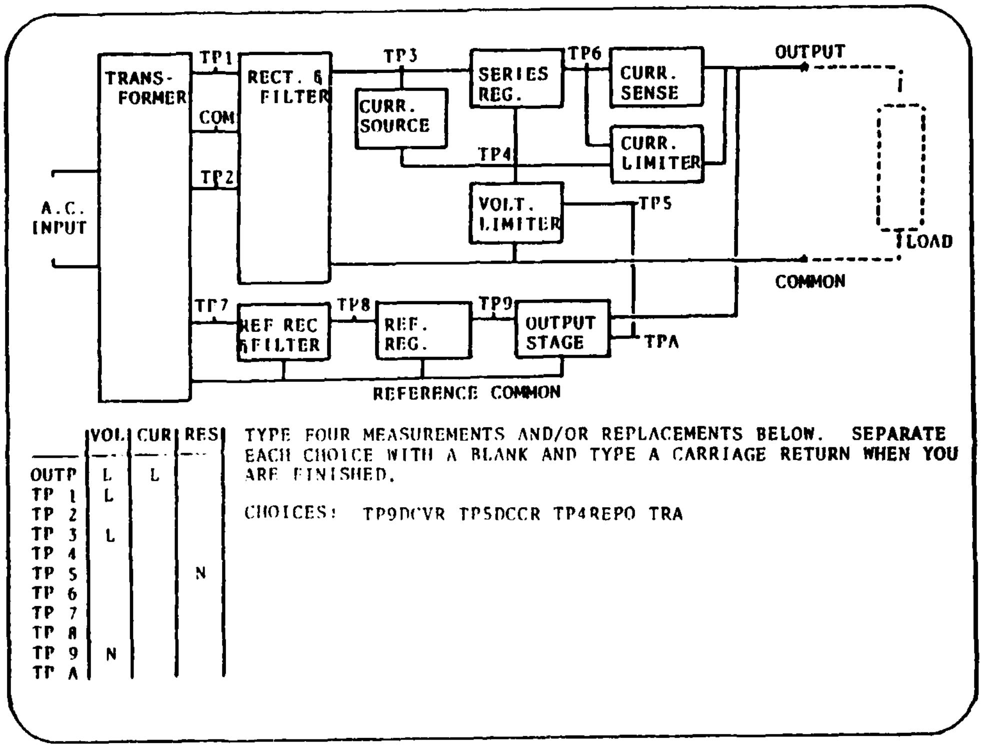
	VOL	CUR	RES
OUTP	L	L	
TP 1			
TP 2			
TP 3			
TP 4			N
TP 5			
TP 6			
TP 7			
TP 8			
TP 9			
TP A			

HERE ARE THE LAST TWO ACTIONS CONSIDERED BY THE EXPERT:

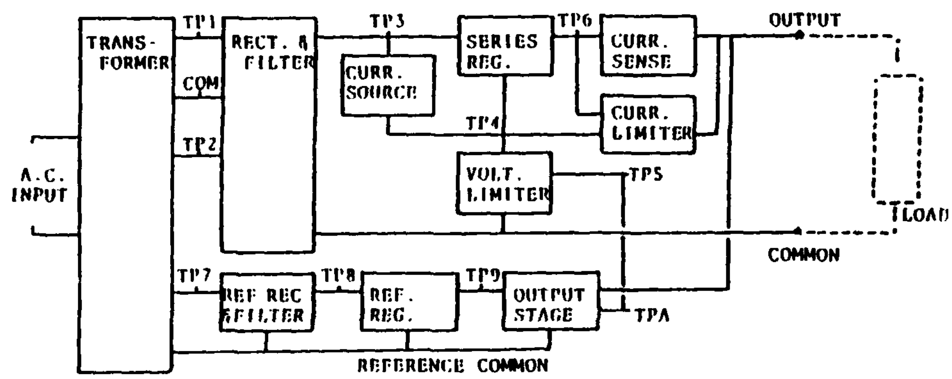
	ACTION	OUTCOME	PROB.	FAULTS ELIM.	COST
3)	TPSDCCR	L	+.67	3/7	8
		N	0	0/7	
		H	+.32	4/7	
4)	TP9DCCR	L	+.32	4/7	4
		N	+.67	3/7	

PRESS "RETURN" TO CONTINUE.
H

Further help can be obtained at this point, which would provide a list of the four actions, ranked in terms of their multi-attribute utilities. If help is not selected, the program requests the student to list four considerations, which need not be the same as those of the expert, and then select one of them for implementation. After having taken several measurements, the student is again asked to select four possible actions.



The student is asked to select an action, using the listed attribute levels as a guide. The student selects replacement of the faulty module by typing "TRA" followed by "RETURN."



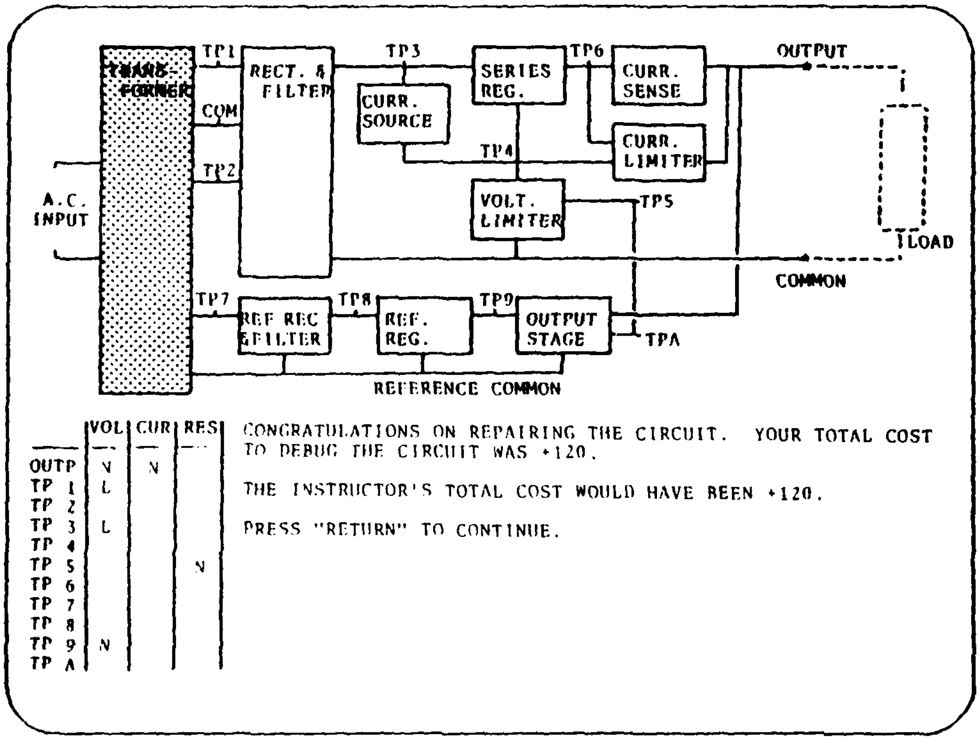
	VOL	CUR	RES
OUTP	L	L	
TP 1	L		
TP 2			
TP 3	L		
TP 4			N
TP 5			
TP 6			
TP 7			
TP 8			
TP 9	N		
TP A			

LISTED BELOW ARE THE FOUR CONSIDERED ACTIONS AND THEIR ATTRIBUTE LEVELS.

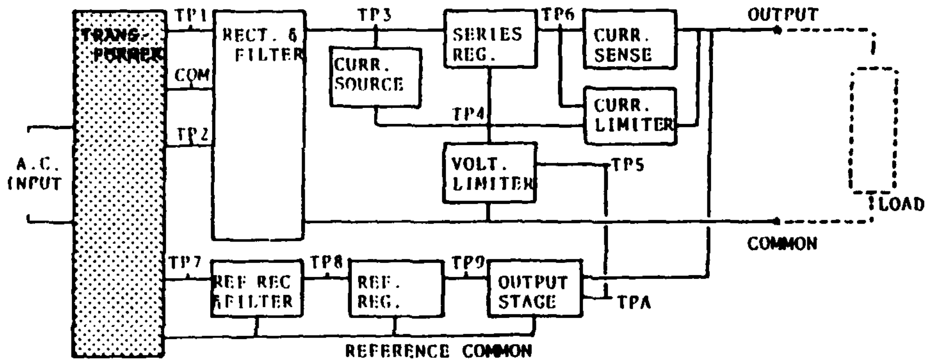
	ACTION	DECREASE IN UNCERTAINTY	FAULT ISOLATION	COST
1.	TP9DCVR	+.40	+.33	+4.00
2.	TP5DCCR	+.40	+.33	+8.00
3.	TP4REPO	+.41	+.43	+10.00
4.	TRA	+.28	+.19	+98.00

TO SELECT AN ACTION, TYPE ITS NAME, THEN PRESS "RETURN."
TRA

The module is enhanced on the display to indicate that it has been replaced. If the replaced module correctly repairs the circuit, the output measurements in the fault table will be changed from low readings to normal readings, as indicated below. The student also will be given feedback to the effect that the circuit has been repaired, and the student's cost involved in troubleshooting the circuit will be compared to that of the instructor.



Comments are displayed to the student stressing considerations to improve performance.

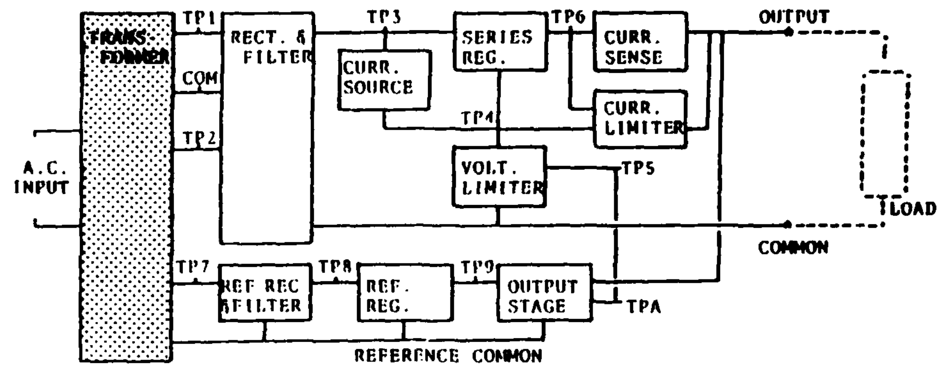


	VOL	CUR	RES
OUTP	N	N	
TP 1	L		
TP 2			
TP 3	L		
TP 4			N
TP 5			
TP 6			
TP 7			
TP 8			
TP 9	N		
TP A			

YOUR CHOICES INDICATE THAT YOU ARE INCONSISTENT IN YOUR TROUBLESHOOTING STRATEGY. BEFORE MAKING A CHOICE, CONSIDER CAREFULLY THE UNCERTAINTY REDUCTION, FAULT ISOLATION, AND COSTS ASSOCIATED WITH EACH CHOICE.

PRESS "RETURN" TO CONTINUE.

Display of comments to the student continues. The student will now begin another troubleshooting problem.



	VOL	CUR	RES
OUTP	N	N	
TP 1			
TP 2	N		
TP 3	L		
TP 4			N
TP 5			
TP 6			
TP 7			
TP 8			
TP 9	N		
TP A			

YOU APPEARED TO OVEREMPHASIZE:
UNCERTAINTY REDUCTION & FAULT ISOLATION

AND UNDEREMPHASIZE:
COST

PRESS "RETURN" TO CONTINUE.

At the conclusion of each problem, the student's performance data are printed out on a teletype and a new problem is presented until the session ends, whether as a result of completing a certain number of problems, or because the student has become an expert troubleshooter. An example of an actual print-out for the first two problems of a session is shown in Table 2-3.

FIGURE 1

ACTS 79 TROUBLESHOOTING OBJECTIVE

```
                    PERFORMANCE REPORT (CURRENT FAULT)
STUDENT:                      AGE:                DATE:
CIRCUIT:   1       FAULT:     1
HELP AVAILABLE: YES            FEEDBACK AVAILABLE: YES
STUDENT INPUT SEQUENCE:                          ACTION-OUTCOMES
     TP5DCVR                                             L
     TP4REPO                                             N
     TP3ACVR                                             L
     TP1ACVR                                             L
     TRA                                                 F
STUDENT WEIGHTS:       +.45        +.88        +.07
EXPERT WEIGHTS:        +.70        +.70          0
CONVERGENCE ACHIEVED: NO               CLOSE TO EXPERT:  NO
UTILITY RATIOS:    STUDENT:    +5.76      +11.32
UTILITY DIFFERENCES:    +.25        -.18        -.08
SLIDING WINDOW PERFORMANCE:
    TRAININGS:  1/20   TOTAL ADJUSTMENT:
SIMU. SUBJ. DRIVING WEIGHTS:         +1.00       +1.00       +1.00
PROBLEM COST:+0.1240E+03
TOTAL COST: +0.1240E+03
                   ACTS 79 TROUBLESHOOTING OBJECTIVE


                    PERFORMANCE REPORT (CURRENT FAULT)
STUDENT:                      AGE:                DATE:
CIRCUIT:   1       FAULT:     2
HELP AVAILABLE: YES            FEEDBACK AVAILABLE: YES
STUDENT INPUT SEQUENCE:                          ACTION-OUTCOMES
     TP9DCVR                                             N
     TP3ACVR                                             L
     TP1ACVR                                             N
STUDENT WEIGHTS:       +.45        +.89        -.02
EXPERT WEIGHTS:        +.70        +.70          0
CONVERGENCE ACHIEVED: NO               CLOSE TO EXPERT:  NO
UTILITY RATIOS:    STUDENT:   -19.22      -37.74
UTILITY DIFFERENCES:    +.25        -.18        +.01.
       0    OW PERFORMANCE:
    TRAININGS:  1/20   TOTAL ADJUSTMENT:
SIMU. SUBJ. DRIVING WEIGHTS:         +1.00       +1.00       +1.00
PROBLEM COST:  +82.00
TOTAL COST:   +82.00
```

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